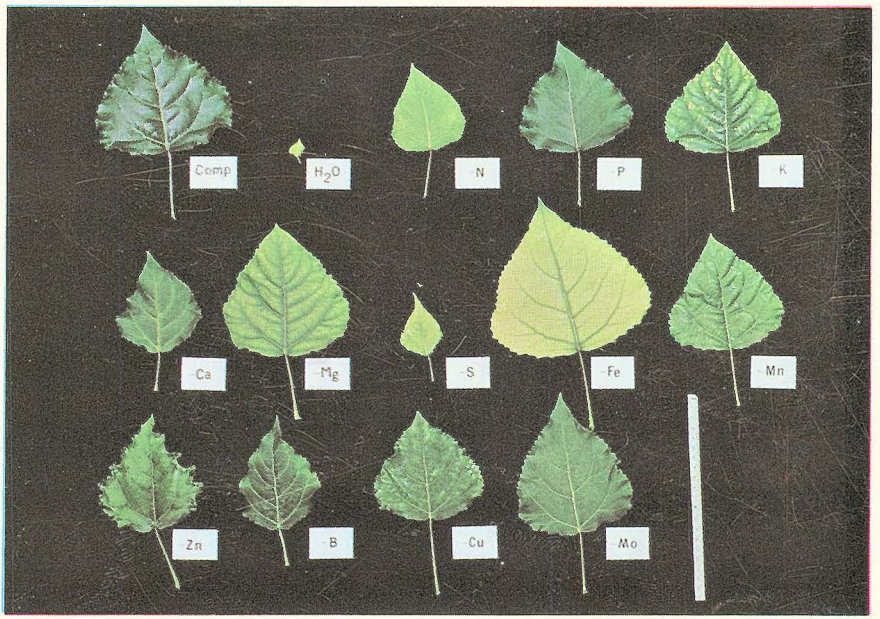

DEFICIENCY SYMPTOMS OF SOME FOREST TREES

JOHN HACSKAYLO, R. F. FINN,

and J. P. VIMMERSTEDT

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DEFICIENCY SYMPTOMS OF SOME FOREST TREES

JOHN HACSKAYLO, R. F. FINN, and J. P. VIMMERSTEDT[1]

INTRODUCTION

This is a report of work on mineral nutrition by Dr. John Hacskaylo and his students during a 10-year period prior to his death. The junior authors believe this information will be useful to practicing foresters, nurserymen, and others concerned with growing trees.

Plants require a number of elements to complete their life cycle. Some elements, the macronutrients, are needed in relatively large quantities and others, the micronutrients, only in small amounts.

Although micronutrients are needed in smaller quantities than macronutrients, this does not mean that the micronutrients are less essential to the plant for carrying on its various physiological functions. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) are needed in fairly large quantities for normal growth and development. Lesser amounts of the micronutrients iron (Fe), manganese (Mn), zinc (Zn), boron (B), copper (Cu), and molybdenum (Mo) are required. The following description of elemental function is from Bonner and Varner (1), Fruton and Simmonds (4), Kramer and Kozlowski (10), and Wallace (12).

Nitrogen is an important component of chlorophyll, enzymes and structural proteins, nucleic acids, and other organic compounds. Since these nitrogen-containing compounds make up 40-50 percent of the dry matter of protoplasm, N is required in relatively large amounts. Nitrogen is mobile in trees and moves from older tissue to vital growing areas. Thus deficiency symptoms appear first in the older parts of plants.

Phosphorus also has a central role in tree growth processes. The high energy phosphate bonds of adenosine triphosphate (ATP) are the universal coin of energy transfer in biochemical systems. Phosphate groups join nucleosides into the macromolecules of ribonucleic acids (RNA) and deoxypentose nucleic acids (DNA). These large molecules mediate protein synthesis and transfer of genetic information. Life processes involving phosphorus include fat, carbohydrate, and protein metabo-

[1]Dr. John Hacskaylo, professor of forestry at the Ohio Agricultural Research and Development Center, died Sept. 11, 1965. Dr. Finn is project leader, North Central Forest Experiment Station, U. S. Forest Service, Ames, Iowa, and Dr. Vimmerstedt is associate professor of forestry, Ohio Agricultural Research and Development Center.

lism; seed germination; fruit ripening; and root development. P is fairly mobile in plants.

Potassium occurs in all plant parts in quite large amounts but is not a constituent of important plant compounds such as carbohydrates, proteins, etc. Instead, it is present in soluble form and probably helps to maintain internal osmotic balance. Although the specific role of potassium is poorly understood, it may function in carbohydrate and protein synthesis, regulation of cell water and transpiration, and as a chemical condensing agent and enzyme activator. Since K is highly mobile, deficiency symptoms appear first in older tissues and progress toward the growing points.

Calcium occurs in cell walls as calcium pectate and elsewhere in plants as calcium oxalate. Calcium is essential for the structural and functional integrity of plant cell membranes (3). Ca is actively involved in growth and development. Since it is quite immobile, a deficiency leads to injury of meristems.

Magnesium activates a number of enzymes involved in transphosphorylation and is a constituent of the vital metalloprotein, chlorophyll. Mg is readily translocated and older tissues are the first to exhibit deficiency symptoms.

Sulfur is found in the amino acids cystein, cystine, and methionine, which occur in many proteins. The disulfide linkage of cystine is important in maintaining protein configuration and the sulfhydryl group of the cystein moiety in coenzyme A is important in many biochemical reactions. Sulfur is less mobile than N, P, K, or Mg.

Iron is closely related to chlorophyll formation. It is a constituent of respiratory enzyme systems and of oxidation systems coupled with nitrate reduction. Iron is relatively immobile.

Manganese is associated with chlorophyll formation and with oxygen evolution in photosynthesis. It functions as a catalyst in enzyme systems involving oxidation-reduction reactions. Mn is relatively immobile.

Boron apparently has many roles in the plant, including association with sugar translocation, respiration, reproduction, and water relations of cells. A deficiency causes injury to stem tips.

Copper is associated with chloroplasts and proteins but the role of copper in plants is not clear. It is a metal constituent of some oxidation-reduction enzyme systems. Proteolysis may result from copper deficiency.

Zinc functions in a number of enzyme systems involving different types of reactions. Hence, zinc deficiency symptoms may be varied.

Molybdenum is an essential constituent of nitrate reductase systems in plants and is involved in nitrogen fixation by legumes.

The illustrations in this publication show the effects of omitting a specific macronutrient or micronutrient from otherwise complete, bal-

anced nutrient solutions for black walnut (*Juglans nigra* L.), eastern cottonwood (*Populus deltoides* Bartr.), black locust (*Robinia pseudoacacia* L.). and sweetgum (*Liquidambar styraciflua* L.). For Scots pine (*Pinus sylvestris* L.), the effects of deficiencies of macronutrients are given. Lime-induced chlorosis is illustrated for pin oak (*Quercus palustris* L.).

Nutrient deficiencies often produce characteristic visual symptoms. Sometimes, however, symptoms for two or more elements are so similar that it is difficult to distinguish between them. In these cases, chemical analyses of the plant tissues will usually identify the deficient element. This report includes chemical analyses of adequately nourished and deficiently nourished black walnut, eastern cottonwood, black locust, and Scots pine seedlings.

MATERIALS AND METHODS

Details of experimental procedures are given in the following references: Hacskaylo and Struthers (7), Goslin (5), Hacskaylo (6), and Hacskaylo and Vimmerstedt (8).

In brief, seedlings or cuttings were first established in sand flats and then were transferred to 3-gallon, polyethylene-lined crocks. The crocks were filled with HCl-washed, cracked, silica quartz and were equipped for continuous aeration.

After being transferred to the crocks, plants were maintained on deionized water for 2 weeks and then on the complete nutrient solution at ½ normal concentration for 4 weeks. Subsequently, the complete nutrient solutions were drained off and replaced with nutrient solutions lacking one of the essential elements. The plants were grown in these solutions until deficiency symptoms became severe.

Plants grown in complete nutrient solutions were included as standards for comparison and others grown in deionized water served as checks on contamination. Nutrient solutions were changed periodically during the experiments. Deionized water was added as needed to replace evapotranspiration losses.

Nutrient solutions were prepared from reagent grade chemicals and deionized water. Solution pH was initially adjusted to 5.4 with 0.1% NaOH. The nutrient solutions are referred to as complete (containing all macro- and micronutrients), —N, —P, —K, —Ca, —Mg, —S, —Fe, —Mn, —Zn, —B, —Cu, —Mo, and xxH_2O (deionized water). Table I of the Appendix lists the chemical composition of the various nutrient solutions.

The plant material for cottonwood and black locust was genetically uniform. Cottonwood plants were obtained by rooting cuttings of a Wisconsin clone and black locust from root-suckers of a single plant. Black walnut plants were grown from seed of a southeast Iowa source.

Fig. 1.—Greenhouse arrangement of cottonwood deficiency experiment.

Scots pine plants were from seed of a New York State planting of the Riga strain. The origin of the sweetgum seed is not known.

All plants were grown in a greenhouse equipped with fluorescent lights to maintain a minimum light intensity of 300 foot candles during a 15-hour photoperiod. Air temperatures ranged from 70° to 100° F. during the day and from 60° to 80° F. at night.

For each species, one replication consisted of 14 crocks, one of each of the deficient nutrient solutions, one of the complete solution, and one of deionized water. The black walnut and cottonwood series were replicated three times and the black locust, sweetgum, and Scots pine four times.

Figure 1 illustrates the general experimental setup for cottonwood. Setups for the other species were similar.

Upon terminating the experiments, representative plants were photographed. Black walnut, black locust, cottonwood, and Scots pine were separated into roots, stems, and leaves, oven dried, and ground to pass a 60 mesh screen. Nitrogen contents of walnut, cottonwood, and locust tissues were determined by Kjeldahl digestion (11) and sulfur by the method of Butters and Chenery (2). Concentrations of P,

K, Ca, Mg, Fe, Mn, Zn, B, Cu, and Mo in the tissues of walnut, cottonwood, locust, and Scots pine were determined by spectrographic analysis (9). N and S contents of Scots pine were not measured and no chemical analyses of sweetgum were made.

All leaves on a particular deficient plant were included in the chemical analyses rather than just the leaves showing the deficiency symptoms. As a result, differences in foliar concentrations are not as great between the complete and deficient plants as they probably would have been if the comparison had been made between leaves from the complete and those leaves exhibiting deficiency symptoms.

Pin oak was studied by a different method from the above (7). Some pin oak trees on the grounds of the Ohio Agricultural Research and Development Center had chlorotic leaves in 1958 and others did not. Seven trees, ranging in appearance from normal to severely chlorotic, were selected for study. Leaves on these trees were dipped in dilute solutions of $FeSO_4$, $Ca(NO_3)_2$, $ZnSO_4$, KNO_3, NaCl, KH_2PO_4, or a dilute mixture of all micronutrients except iron. Within 10 days, chlorotic leaves treated with iron turned a healthy green. This identified the symptoms as due to iron deficiency.

Investigation revealed that the normally acid soil had been heavily limed some years earlier. Since the symptoms could be corrected either by an application of chelated iron or by acidifying the soil with H_2SO_4, this was an example of lime-induced chlorosis. The symptoms of this disorder are included in the section on iron deficiencies of hardwoods.

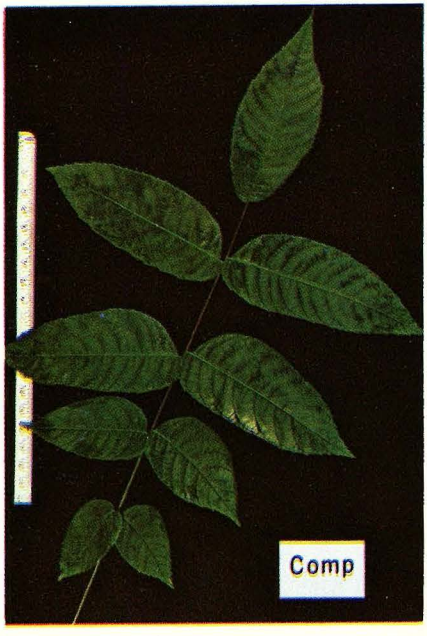
RESULTS FOR HARDWOODS

Abnormal leaf color and other leaf characteristics of seedlings growing in a nutrient solution from which one essential element was omitted are judged against normal leaves from seedlings growing in a complete nutrient solution which contains all the essential inorganic nutrient elements.

Normal leaves from seedlings of black walnut, black locust, cottonwood, and sweetgum have a healthy green color and normal size and shape (Figure 2).

FOLIAR SYMPTOMS AND CHEMICAL COMPOSITION OF PLANTS

Appearance of black walnut, black locust, cottonwood and sweetgum leaves from plants grown in nutrient solutions deficient in a single essential element is described and illustrated in the following pages. Abbreviated tables of chemical analyses, comparing the concentration of the deficient element in the leaves, stems, and roots of the plants grown in nutrient-deficient and complete nutrient solutions, are included. Detailed chemical analyses are given in Appendix Tables II-V.



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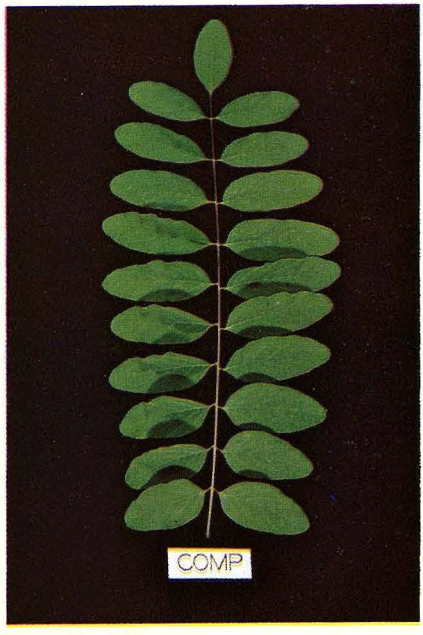

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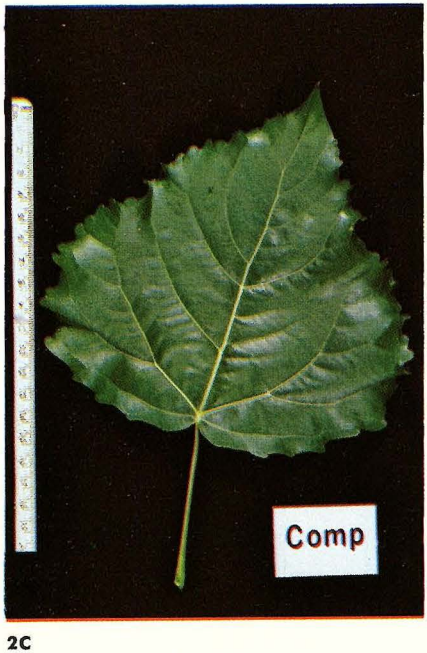

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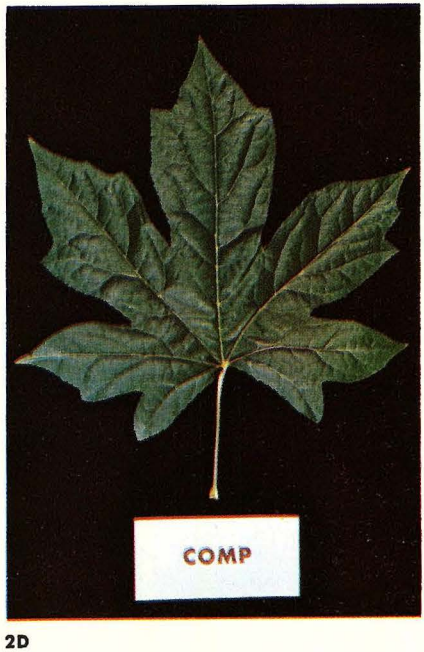


2D

Fig. 2.—Leaves of (A) black walnut, (B) black locust, (C) cottonwood, and (D) sweetgum from plants grown in a complete nutrient solution.

Nitrogen

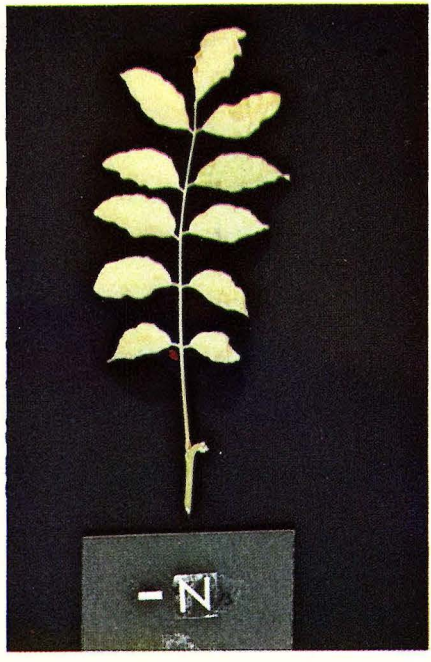
Omission of nitrogen from the nutrient solution led to a general reduction in the size of leaves and in the number of leaflets (Figure 3). The color varied from greenish yellow for sweetgum to yellow for black locust. Petioles of black walnut were yellowish and sweetgum petioles were red. Black locust leaflets were wrinkled.

Nitrogen concentrations in the leaves, stems, and roots of black walnut and eastern cottonwood were considerably lower in the seedlings from the —N solution than in those from the complete solution (Table 1). Concentration of N in roots of black locust from the —N solution was actually higher than in roots from the complete. Black locust roots in the —N nutrient solution were heavily nodulated. Thus some nitrogen was supplied to these plants through symbiotic nitrogen fixation. Fixation was not sufficient to supply all the needed N and deficiency symptoms developed. Although concentrations of N were higher in the roots of nitrogen-deficient black locust, top growth was severely reduced.

TABLE 1.—Nitrogen Concentrations in Normal and Deficient Seedlings (Percent O.D.W.).

Species	Leaves		Stems		Roots	
	Complete	— N	Complete	— N	Complete	— N
Black walnut	3.35	2.96	1.86	1.62	2.78	1.85
Eastern cottonwood	2.86	1.38	1.01	0.41	1.27	0.50
Black locust	2.89	2.07	0.94	0.93	1.85	2.06

3A



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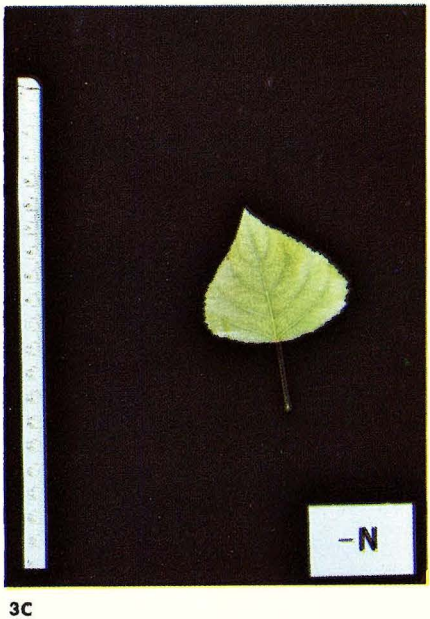

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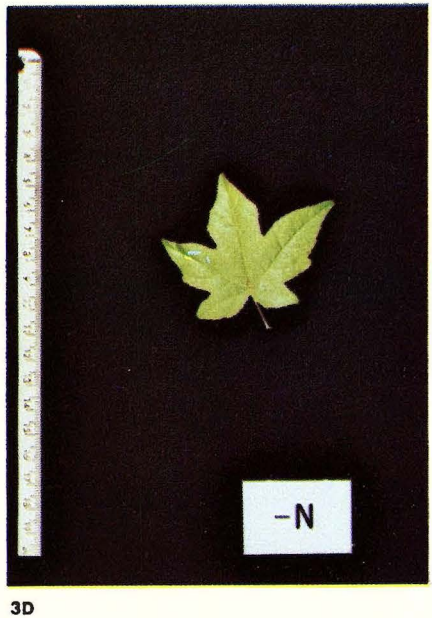


3D

Fig. 3.—Leaves of (A) black walnut, (B) black locust, (C) cottonwood, and (D) sweetgum from plants grown in a nitrogen-deficient nutrient solution.

Phosphorus

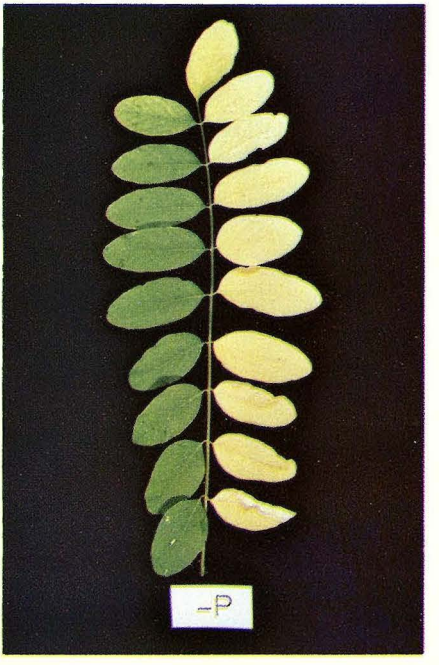
Phosphorus-deficient trees showed various symptoms (Figure 4). Leaf size was not greatly reduced except for black walnut. The veins in black walnut leaves were light yellow; interveinal areas were green or reddish brown to purplish red. Overall appearance was variegated. Sweetgum had red petioles and light reddish main veins. The symptoms were not well developed for cottonwood but a slight reddening of the main veins was observed.

In general, phosphorus concentrations of deficient plants were well below those grown in the complete solution (Table 2).

TABLE 2.—Phosphorus Concentrations in Normal and Deficient Seedlings (Percent O.D.W.).

Species	Leaves		Stems		Roots	
	Complete	— P	Complete	— P	Complete	— P
Black walnut	0.34	0.17	0.25	0.13	0.38	0.24
Eastern cottonwood	0.83	0.14	0.43	0.05	0.91	0.10
Black locust	0.44	0.08	0.33	0.06	0.80	0.71

4A



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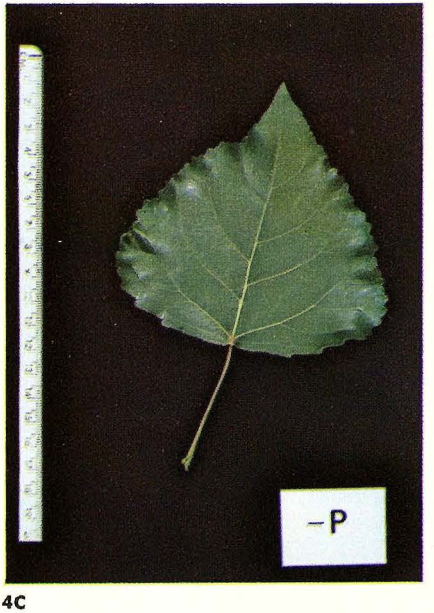

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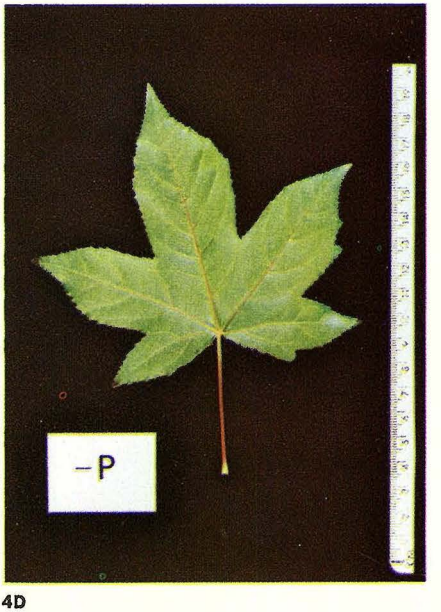


4D

Fig. 4.—Leaves of (A) black walnut, (B) black locust, (C) cottonwood, and (D) sweetgum from plants grown in a phosphorus-deficient nutrient solution.

Potassium

Potassium-deficient leaves were slightly smaller than normal except black walnut leaves, which were much reduced in size and number of leaflets (Figure 5). Deficient black walnut leaves were yellow-green and yellow along most of the leaf margin. The yellowing was especially pronounced on leaflet tips. The tips of sweetgum were fired and other affected areas appeared grayish. Cottonwood leaves had green veins; the interveinal areas were greenish yellow with cream-colored areas.

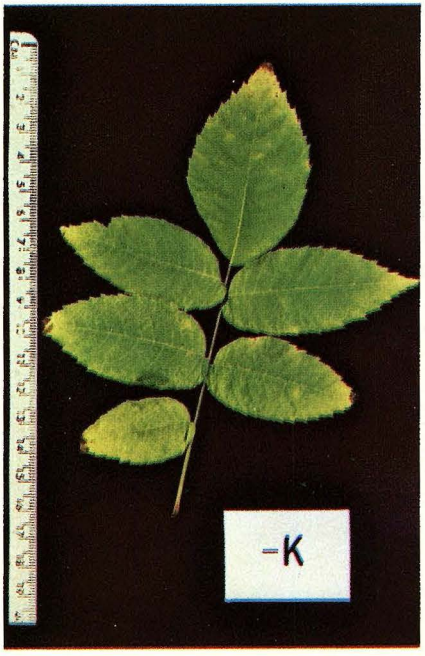
The yellow color characterizing potassium deficiency in black locust leaves was most intense on the bottom leaflets and decreased toward the top. The coloring was fairly uniform on both sides of the rachis.

Potassium concentrations in deficient seedlings were markedly below those of seedlings grown in the complete nutrient solution (Table 3). Unfortunately, tissues of potassium-deficient black walnut were lost and so these analyses are not included.

TABLE 3.—Potassium Concentrations in Normal and Deficient Seedlings (Percent O.D.W.).

Species	Leaves		Stems		Roots	
	Complete	—K	Complete	—K	Complete	—K
Black walnut	1.72	*	0.76	*	1.26	*
Eastern cottonwood	4.59	0.44	1.46	0.20	2.06	0.22
Black locust	2.38	0.54	1.11	0.31	3.03	0.27

*Not determined.



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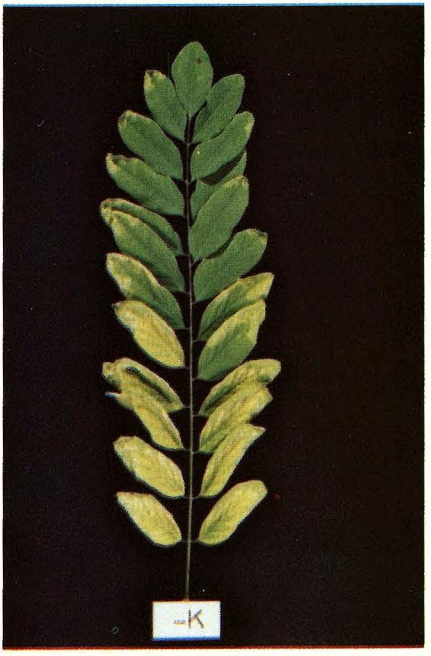

5B

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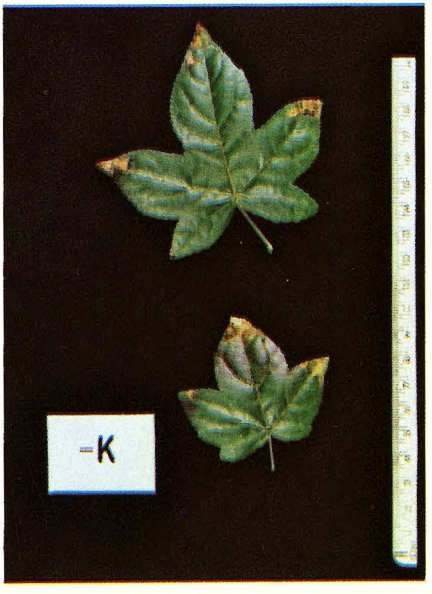


5D

Fig. 5.—Leaves of (A) black walnut, (B) black locust, (C) cottonwood, and (D) sweetgum from plants grown in a potassium-deficient nutrient solution.

Calcium

Figure 6 shows the foliar symptoms when calcium is deficient. There was a marked reduction in the size of black walnut leaves and in the number of leaflets. Some reductions in size of leaves were observed in the other three species.

Calcium-deficient leaves of black walnut appeared yellow-green to an almost uniform cream color. In sweetgum, the petioles were brownish; light brown spots developed along the margins and progressed toward the center. The veins in cottonwood were almost white and the leaves varied from light green to yellow-green. Yellowing of the leaves of black locust progressed from the tips of the leaves toward the bases, beginning at the leaflet margins.

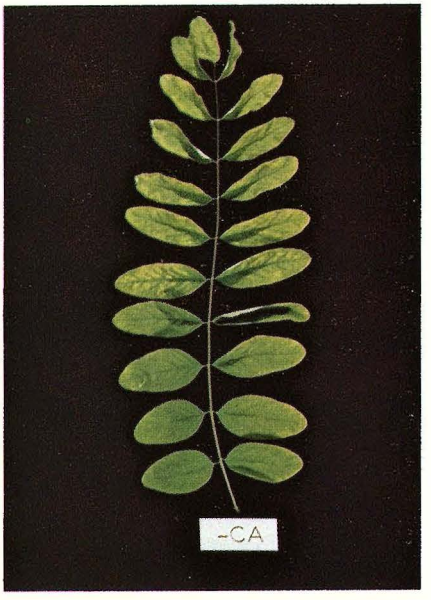
Calcium deficiency resulted in disintegration of the terminal buds and associated tissues in cottonwood and black locust (Figure 7). The terminal leaves of black locust became chlorotic, dwarfed, and delicate. The terminal leaves of cottonwood were small, yellow, and eventually died. These effects on young, fast-growing tissues illustrate the immobility of calcium.

Calcium concentrations of deficient seedlings were greatly reduced (Table 4).

TABLE 4.—Calcium Concentrations in Normal and Deficient Seedlings (Percent O.D.W.).

Species	Leaves		Stems		Roots	
	Complete	— Ca	Complete	— Ca	Complete	— Ca
Black walnut	1.19	0.30	0.42	0.07	0.31	0.05
Eastern cottonwood	0.95	0.20	0.46	0.15	0.83	0.15
Black locust	1.11	0.28	0.44	0.13	1.40	0.21

6A



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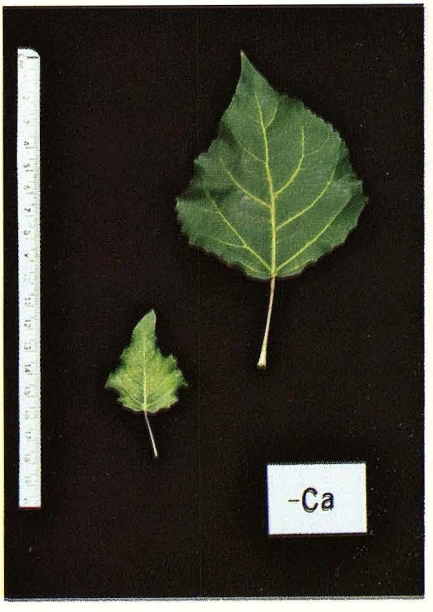

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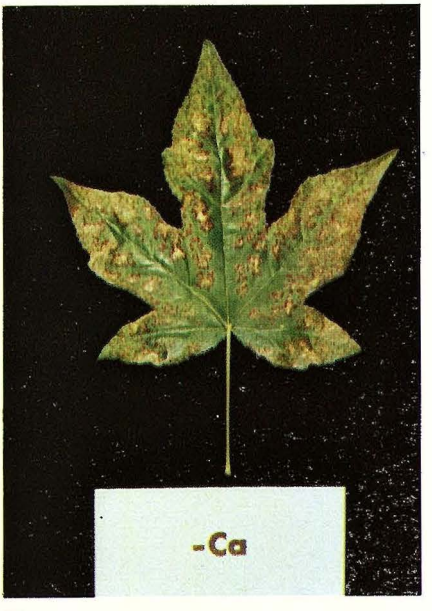
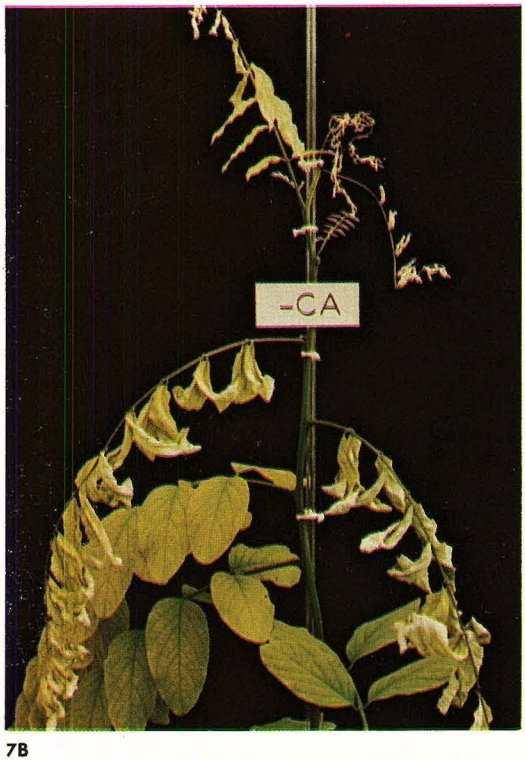


6D

Fig. 6.—Leaves of (A) black walnut, (B) black locust, (C) cottonwood, and (D) sweetgum from plants grown in a calcium-deficient nutrient solution.

7A



7B

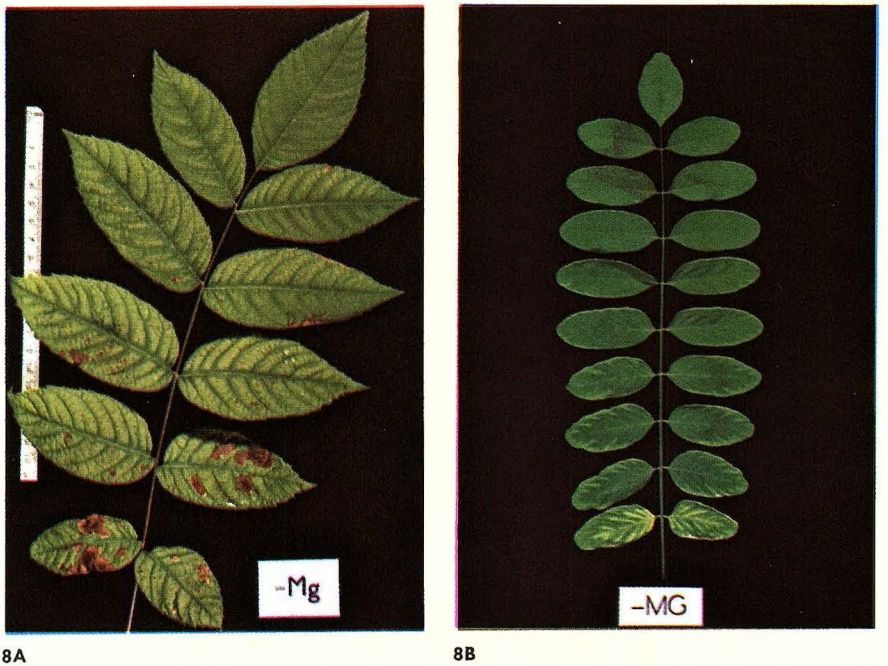
Fig. 7.—Terminal portions of (A) cottonwood and (B) black locust plants, showing effects of Ca deficiency on meristems.

Magnesium

Interveinal areas of magnesium-deficient leaves were pale yellow-green, in contrast to the darker green tissue near the veins (Figure 8). Deficiency symptoms of black locust and black walnut leaves were most pronounced on the basal leaflets, diminishing toward the leaf tips. Concentrations of Mg in deficient seedlings were well below those in plants grown in the complete nutrient solution (Table 5).

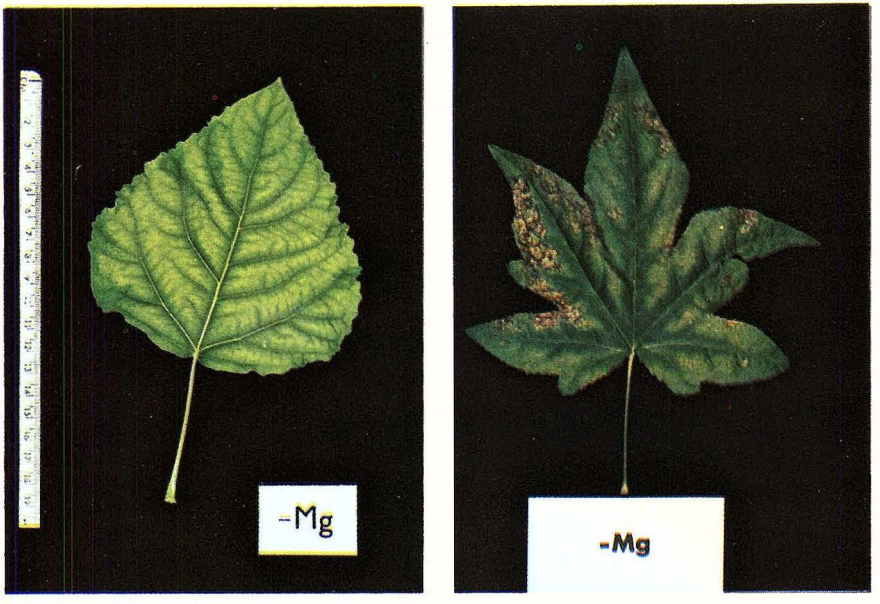
TABLE 5.—Magnesium Concentrations in Normal and Deficient Seedlings (Percent O.D.W.).

Species	Leaves		Stems		Roots	
	Complete	— Mg	Complete	— Mg	Complete	— Mg
Black walnut	0.40	0.06	0.15	0.04	0.17	0.05
Eastern cottonwood	0.49	<0.04	0.17	<0.04	0.24	<0.04
Black locust	0.41	0.20	0.17	0.12	0.65	0.16



8A 8B

Fig. 8.—Leaves of (A) black walnut and (B) black locust from plants grown in a magnesium-deficient nutrient solution.



8C 8D

Fig. 8 (continued).—Leaves of (C) cottonwood and (D) sweetgum from plants grown in a magnesium-deficient nutrient solution.

Sulfur

The pale yellow-green color of leaves resulting from sulfur deficiency is shown in Figure 9.

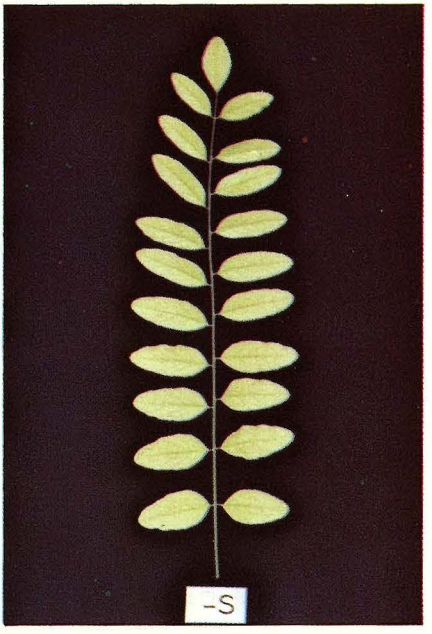
Tissues near the main veins were somewhat darker than the interveinal areas, especially in cottonwood. Sweetgum and cottonwood leaf sizes were markedly reduced but only small reductions were noted for black walnut and black locust.

Sulfur concentrations in normal and deficient seedlings are presented in Table 6.

TABLE 6.—Sulfur Concentrations in Normal and Deficient Seedlings (Percent O.D.W.).

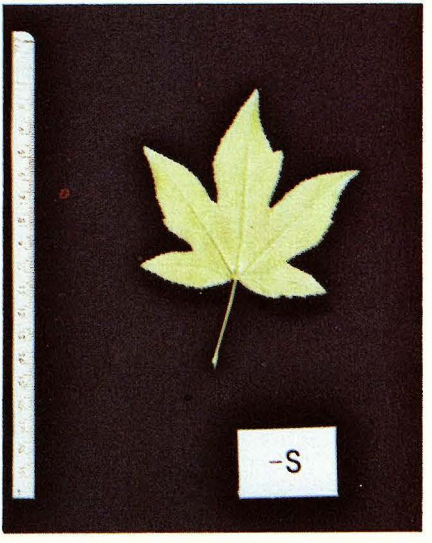
Species	Leaves		Stems		Roots	
	Complete	— S	Complete	— S	Complete	— S
Black walnut	0.20	0.14	0.12	0.02	0.15	0.08
Eastern cottonwood	0.38	0.13	0.05	0.04	0.18	0.04
Black locust	0.16	0.12	0.09	0.04	0.64	0.17

9A



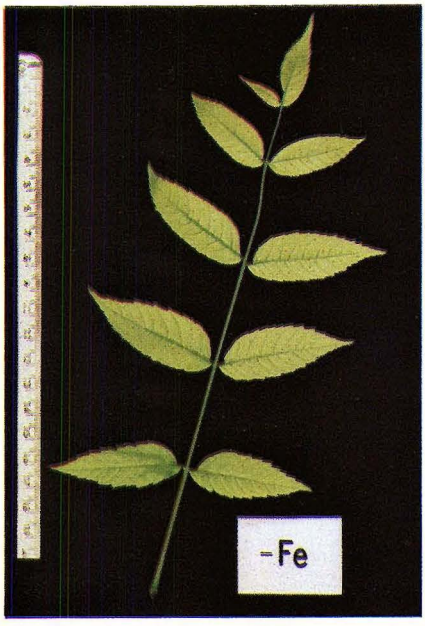
9B

9C

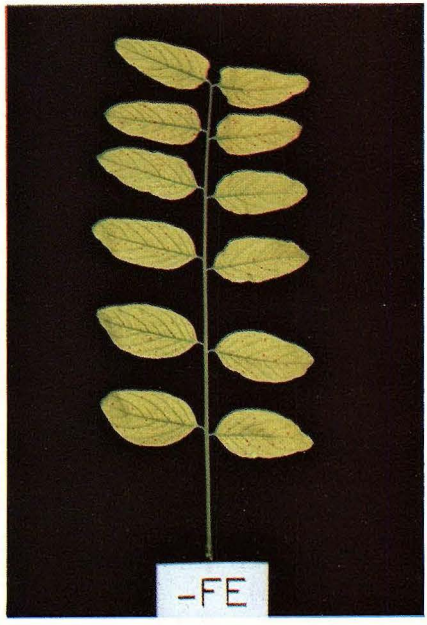


9D

Fig. 9.—Leaves of (A) black walnut, (B) black locust, (C) cottonwood, and (D) sweetgum from plants grown in a sulfur-deficient nutrient solution.

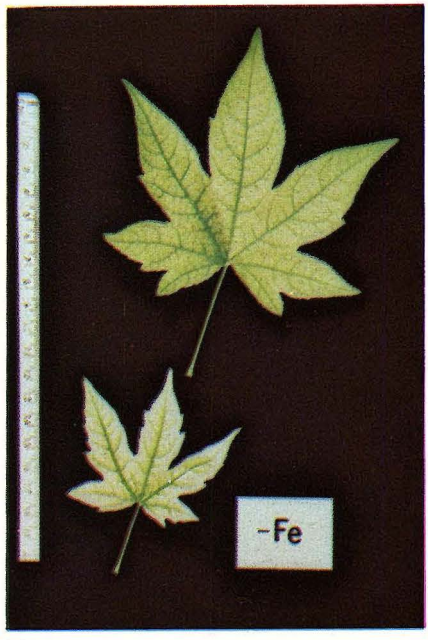


10A



10B

10C



10D

Fig. 10.—Leaves of (A) black walnut, (B) black locust, (C) cottonwood, and (D) sweetgum from plants grown in an iron-deficient nutrient solution.

Iron

Yellow-green to almost white leaves with veins outlined in darker green characterized iron deficiencies of all four species (Figure 10). The leaf rachises of black walnut were green instead of the normal straw color. Leaves of iron-deficient pin oak ranged from yellow-green to cream colored (Figure 11). There was some reduction in leaf size for all species. Symptoms of iron deficiency developed first on terminal leaves because iron is relatively immobile.

Iron concentrations in leaves, stems, and roots are given in Table 7.

TABLE 7.—Iron Concentrations in Normal and Deficient Seedlings (ppm O.D.W.).

Species	Leaves		Stems		Roots	
	Complete	— Fe	Complete	— Fe	Complete	— Fe
Black walnut	202	262	44	32	906	581
Eastern cottonwood	90	33	24	11	925	74
Black locust	135	93	16	19	916	269

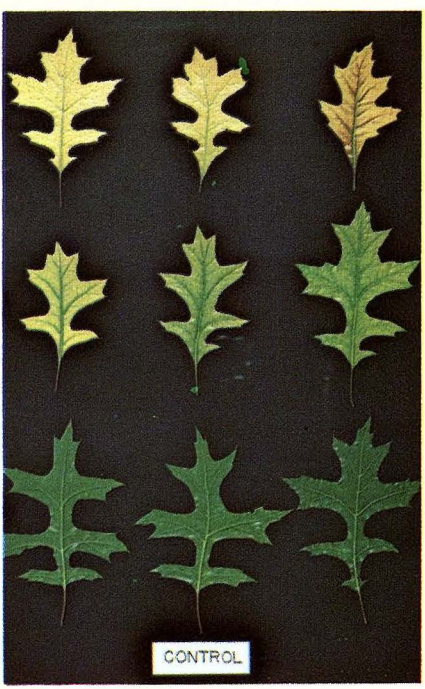


Fig. 11.—Symptoms of iron-chlorosis in pin oak, ranging from very severe in upper left to non-chlorotic in lower right.

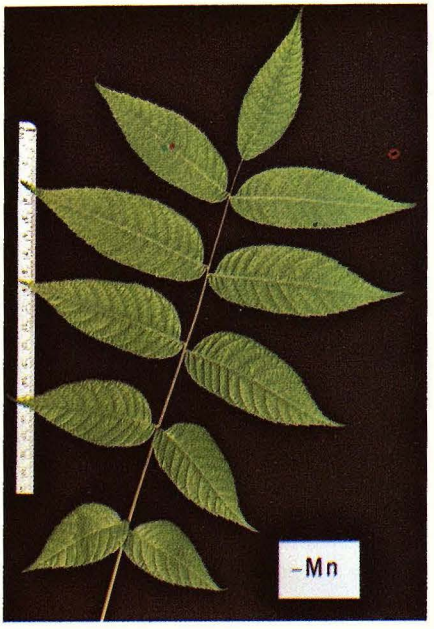
Manganese

Manganese deficiency did not greatly affect leaf sizes. Leaves were yellow-green (Figure 12). Basal leaflets of black walnut and black locust looked paler than those near the leaf tips. Lower leaflets of black locust were rolled or cupped; black walnut leaflets and cottonwood leaves appeared wrinkled.

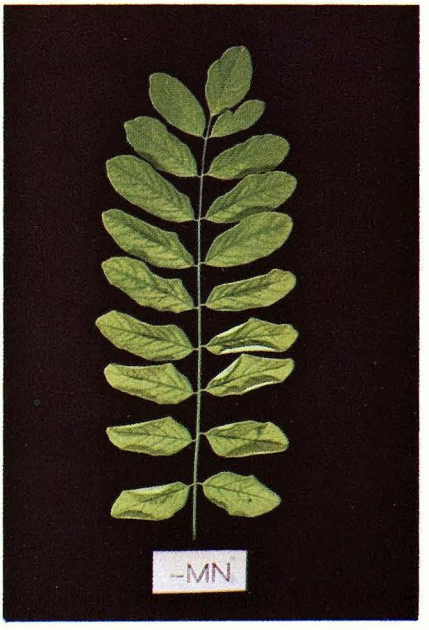
Manganese concentrations in Mn-deficient plants ranged from less than 9 to 20 ppm and in general were well below those in the complete solution (Table 8).

TABLE 8.—Manganese Concentrations in Normal and Deficient Seedlings (ppm O.D.W.).

Species	Leaves		Stems		Roots	
	Complete	— Mn	Complete	— Mn	Complete	— Mn
Black walnut	95	15	26	9	132	11
Eastern cottonwood	49	<9	9	<9	37	<9
Black locust	47	18	17	13	91	18

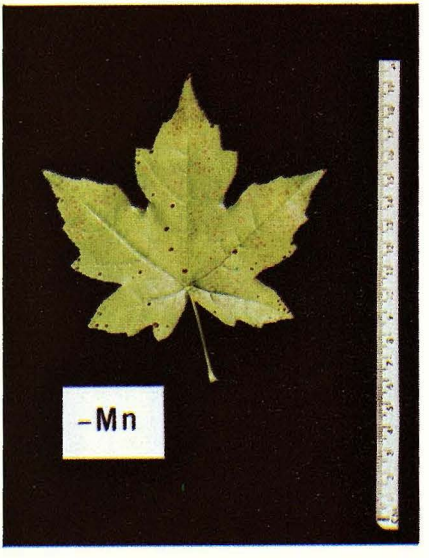


12A



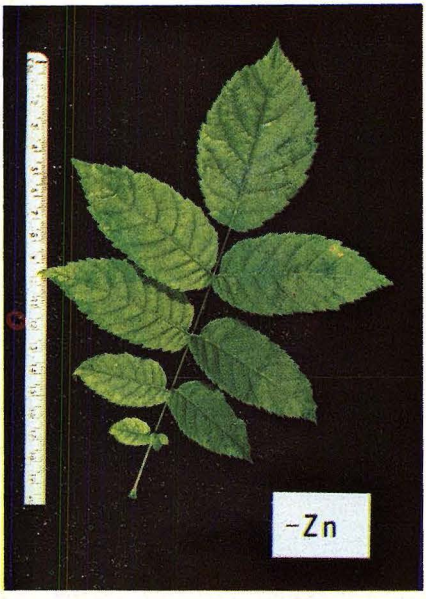
12B

12C

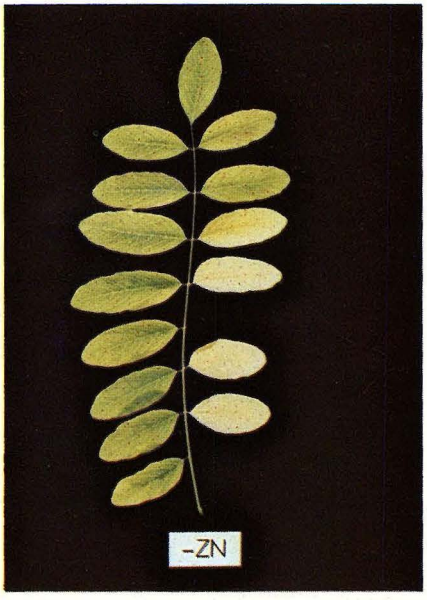


12D

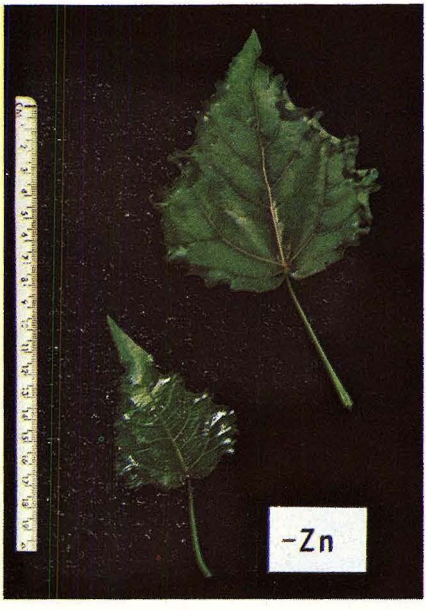
Fig. 12.—Leaves of (A) black walnut, (B) black locust, (C) cottonwood, and (D) sweetgum from plants grown in a manganese-deficient nutrient solution.



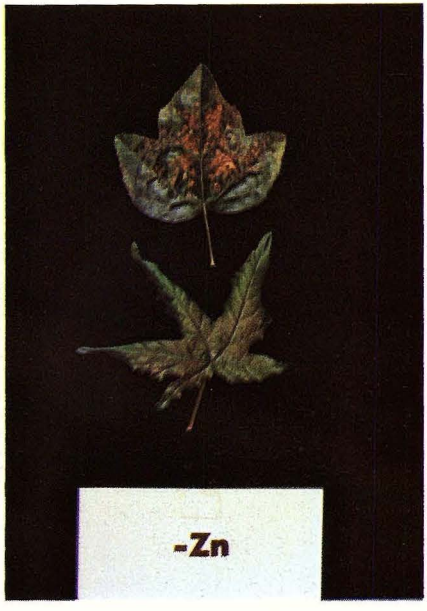
13A



13B



13C



13D

Fig. 13.—Leaves of (A) black walnut, (B) black locust, (C) cottonwood, and (D) sweetgum from plants grown in a zinc-deficient nutrient solution.

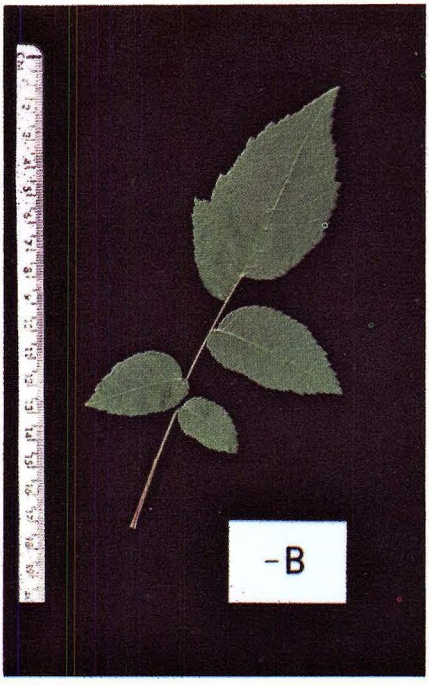
Zinc

Leaves of plants grown in supposedly zinc-deficient nutrient solutions differed in appearance from those of plants grown in the complete solution (Figures 13 and 14). However, concentrations of zinc in the zinc-deficient plants were consistently above those from the complete series (Table 9). Furthermore, cottonwood and locust from the deficient series did not differ markedly from the controls in dry weight or height and diameter growth (8). Therefore, the symptoms illustrated in Figures 13 and 14 are not considered definitive.

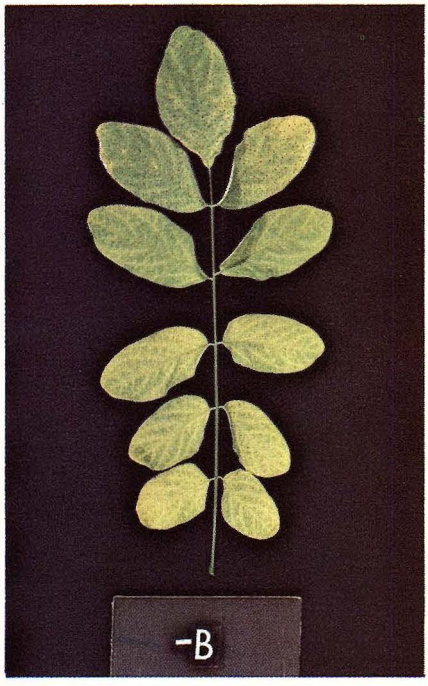
TABLE 9.—Zinc Concentrations in Normal and Deficient Seedlings (ppm O.D.W.).

Species	Leaves		Stems		Roots	
	Complete	— Zn	Complete	— Zn	Complete	— Zn
Black walnut	25	48	11	19	16	33
Eastern cottonwood	14	36	8	26	13	42
Black locust	34	36	19	23	24	28

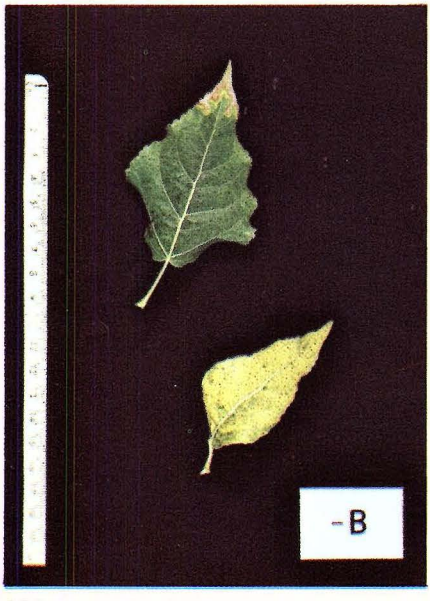
Fig. 14.—Sweetgum growing in a zinc-deficient nutrient solution.



15A



15B



15C

Fig. 15.—Leaves of (A) black walnut, (B) black locust, and (C) cottonwood from plants grown in a boron-deficient nutrient solution.

Fig. 16 (right).—Leaves of sweetgum from plants grown in a boron-deficient nutrient solution.

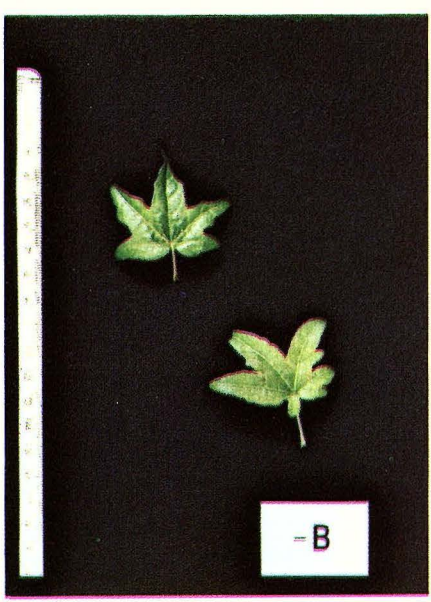
Boron

Leaf symptoms associated with boron deficiency are shown in Figures 15 and 16. There were deformations of some sweetgum and cottonwood leaves and fusions of the terminal and side leaflets of some black walnut leaves, as well as reduction in the number of leaflets. Yellowing of the leaves of black locust, particularly the veins, was most intense on the lower leaflets and decreased toward the tips of the leaves. The terminal buds and associated tissues of cottonwood disintegrated (Figure 17).

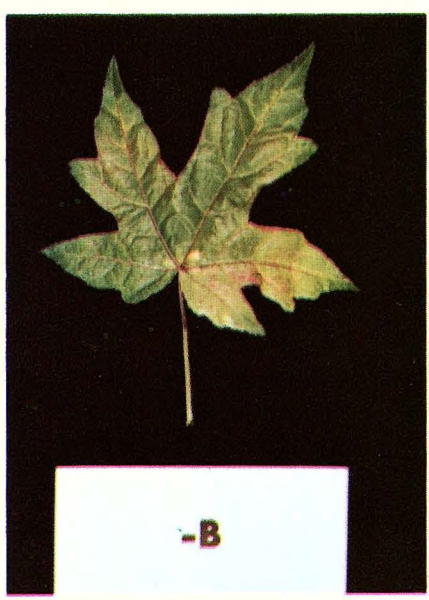
The concentrations of boron in tissues of the deficient cottonwood and black locust were well below the control. In black walnut, there was not much difference in boron concentrations.

TABLE 10.—Boron Concentrations in Normal and Deficient Seedlings (ppm O.D.W.)

Species	Leaves		Stems		Roots	
	Complete	— B	Complete	— B	Complete	— B
Black walnut	41	40	12	21	22	21
Eastern cottonwood	68	9	13	7	15	10
Black locust	73	8	12	7	31	19



16A



16B

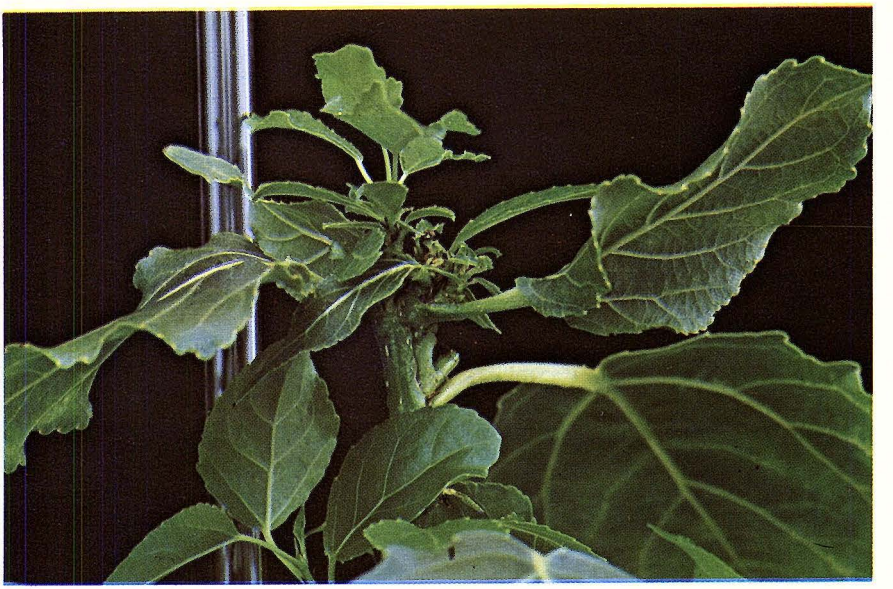


Fig. 17.—Terminal portion of boron-deficient cottonwood, showing rosetting.

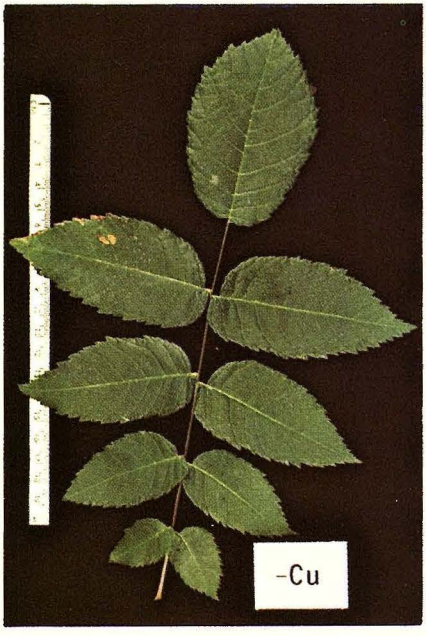
Copper

Copper deficiency symptoms were very pronounced except for black walnut, the leaves of which were only slightly less green than normal (Figures 18 and 19). Sweetgum leaves varied from a bluish green to cream to a greenish gray chlorosis with yellow veins. Cottonwood leaves were shiny green to greenish yellow with dark necrotic areas, especially adjacent to leaf margins. Black locust leaflets were spotted yellow and were yellow along the leaflet margins. The yellowing decreased from the base toward the tip of the leaves. Leaves of cottonwood and sweetgum were smaller than normal.

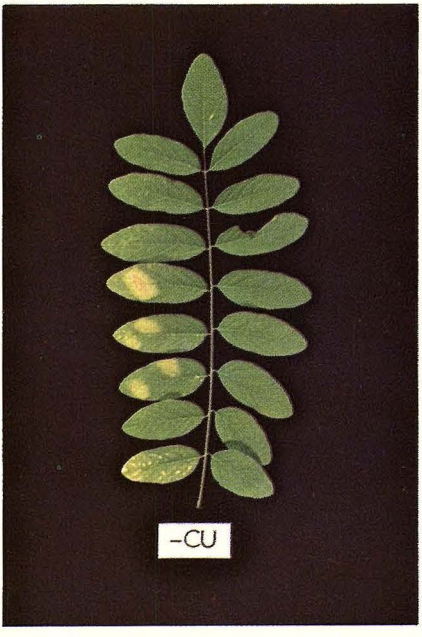
The difference in copper concentration between normal and deficient plants was small (Table 11).

TABLE 11.—Copper Concentrations in Normal and Deficient Seedlings (ppm O.D.W.).

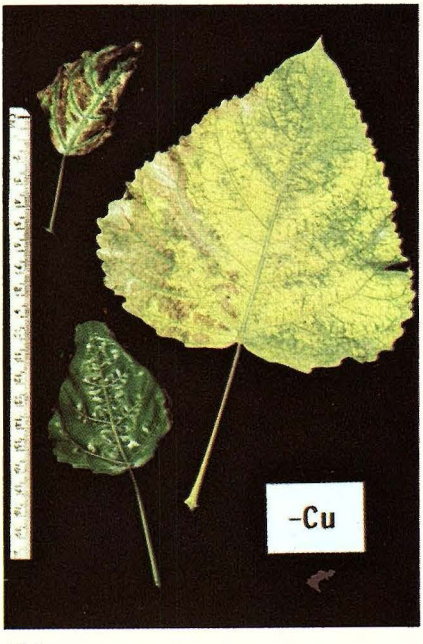
Species	Leaves		Stems		Roots	
	Complete	— Cu	Complete	— Cu	Complete	— Cu
Black walnut	11	8	8	9	11	12
Eastern cottonwood	2	Trace	0.6	2.8	8	<2.5
Black locust	17	19	4	4	16	6



18A



18B



18C

Fig. 18.—Leaves of (A) black walnut, (B) black locust, and (C) cottonwood from plants grown in a copper-deficient nutrient solution.

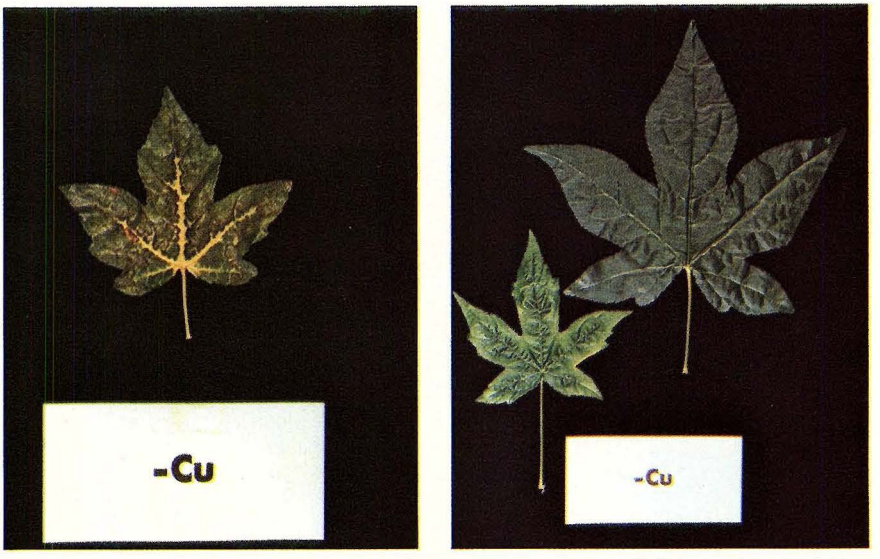
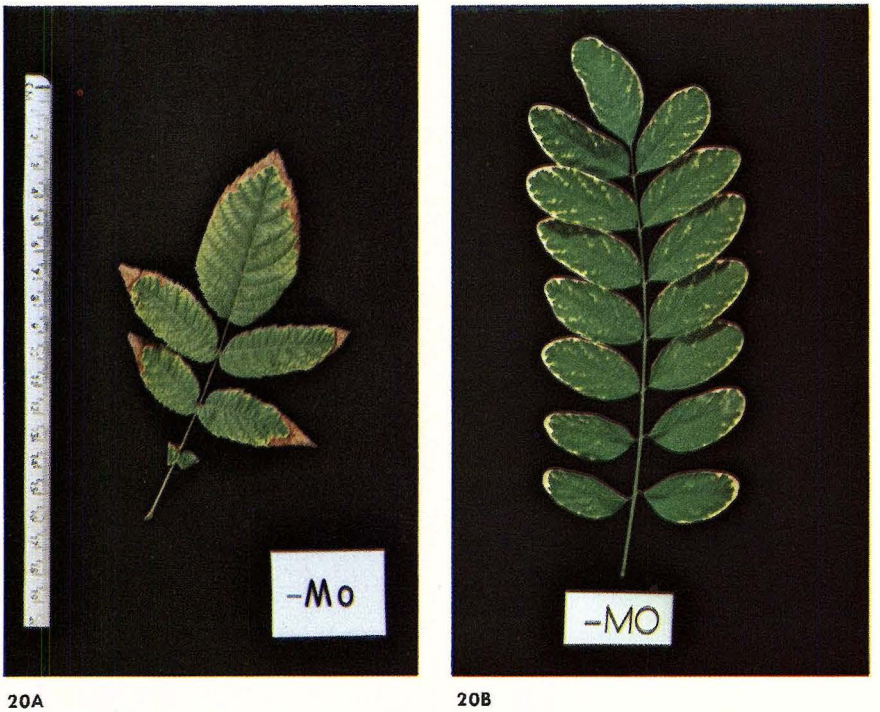


Fig. 19.—Leaves of sweetgum from plants grown in a copper-deficient nutrient solution, showing a range of deficiency symptoms.



20A 20B

Molybdenum

Molybdenum deficiency symptoms for black walnut, eastern cottonwood, black locust, and sweetgum are shown in Figures 20 and 21. In sweetgum, the deficiency results in yellow-green leaves with some tip scorching and progresses to yellow veins and grayish green interveinal areas. Leaflet tips and margins show scorching in black walnut. The leaflet margins of black locust are cream colored with interveinal cream flecking. Flecking also appeared in cottonwood. Reduction in leaf size was pronounced for black walnut but not for the other three species.

Analyses of the leaves for molybdenum are shown in Table 12. In view of the higher Mo concentrations in the deficient cottonwood than in the complete, the visual symptoms described should be used with caution.

TABLE 12.—Molybdenum Concentrations in Normal and Deficient Seedlings (ppm O.D.W.).

Species	Leaves		Stems		Roots	
	Complete	— Mo	Complete	— Mo	Complete	— Mo
Black walnut	2.1	2.3	0.2	0.1	1.2	1.0
Eastern cottonwood	1.3	1.8	0.3	0.7	0.7	1.2
Black locust	1.7	1.2	1.7	0.6	5.0	2.0

20C

Fig. 20 (left and right).—Leaves of (A) black walnut, (B) black locust, and (C) cottonwood from plants grown in a molybdenum-deficient nutrient solution.

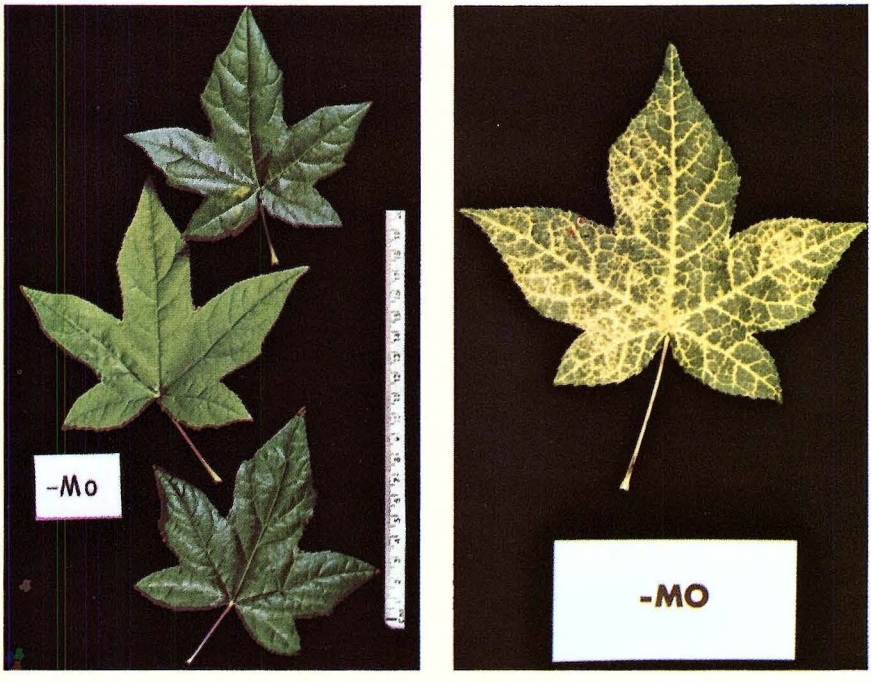


Fig. 21.—Leaves of sweetgum from plants grown in a molybdenum-deficient nutrient solution, showing a range of deficiency symptoms.

EFFECTS OF NUTRIENT DEFICIENCIES ON LEAF SIZE AND DEVELOPMENT

Figures 22 - 28 are composite photographs of walnut, locust, and cottonwood leaves. They show comparative effects of various deficiencies on color, size, and shape of leaves.

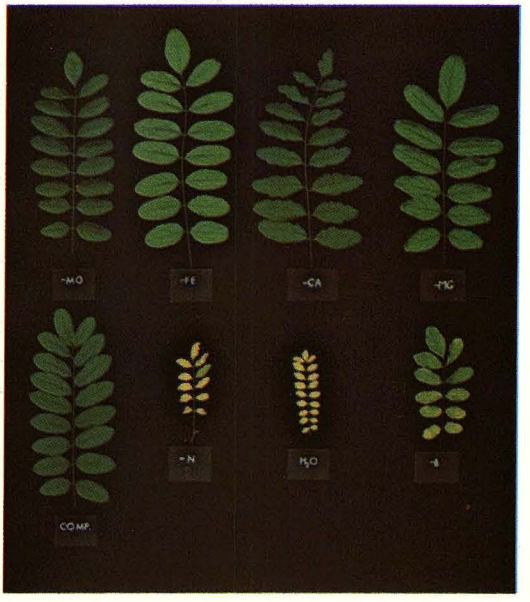
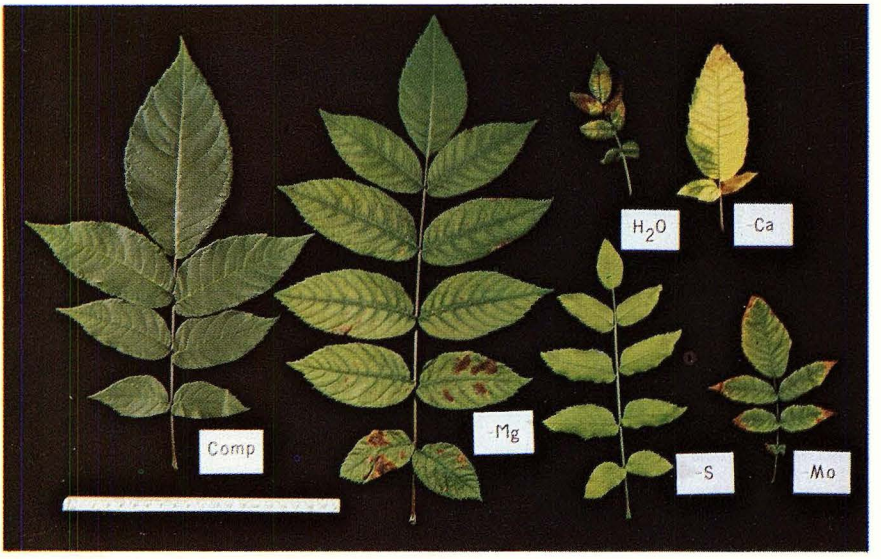


Fig. 22.—Typical leaves of black locust grown in various nutrient solutions. Top row: —Mo; —Fe, —Ca, —Mg; bottom row: complete, —N, deionized water, —B.

Fig. 23.—Typical leaves of black locust grown in various nutrient solutions. Top row: complete, deionized water, —N, —P, —K, —Ca, —Mg; bottom row: —S, —Fe, —Mn, —Cu, —Zn, —B, —Mo.



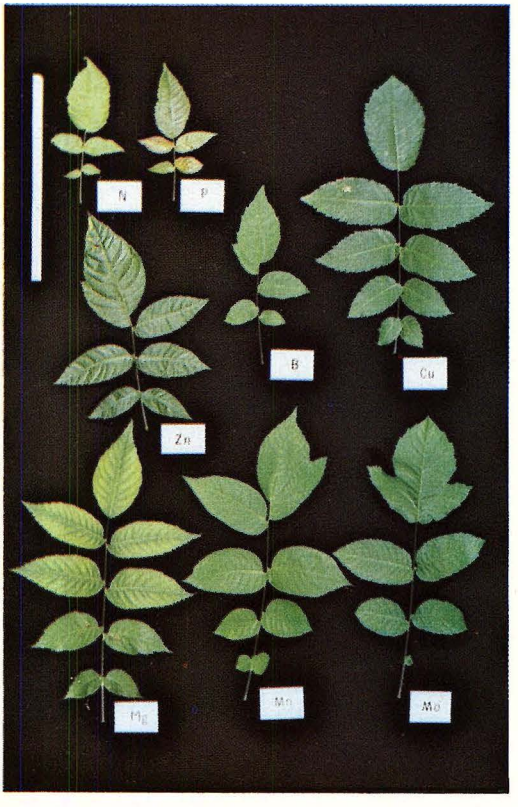


Fig. 24 (above).—Typical leaves of black walnut grown in various nutrient solutions. From left: complete, —Mg; top: deionized water, —Ca; bottom: —S, —Mo.

Fig. 25 (left).—Typical leaves of black walnut grown in various nutrient solutions. Top row: —N, —P; middle row: —Zn, —B, —Cu; bottom row: —Mg, —Mn, —Mo.

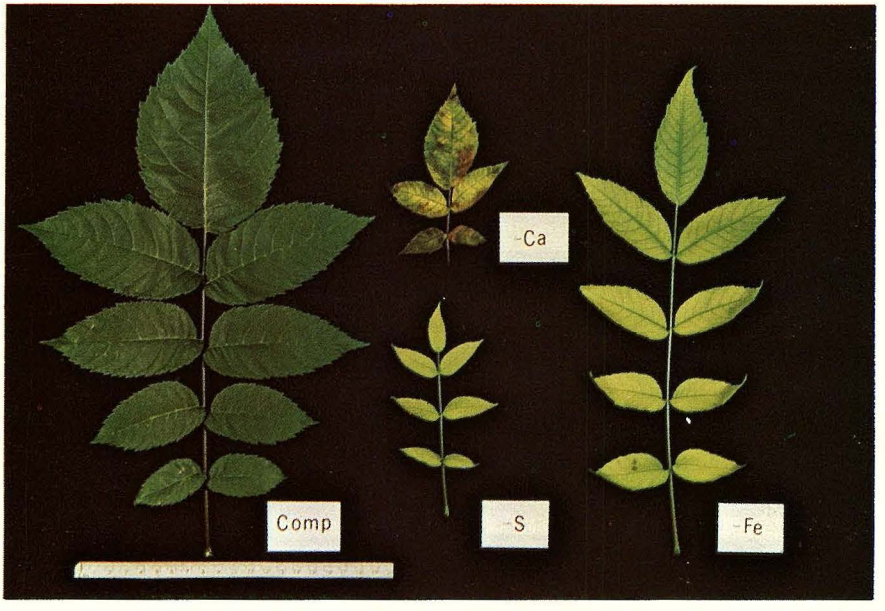


Fig. 26 (above).—Typical leaves of black walnut grown in various nutrient solutions. From left: complete; top: —Ca; bottom: —S, —Fe.

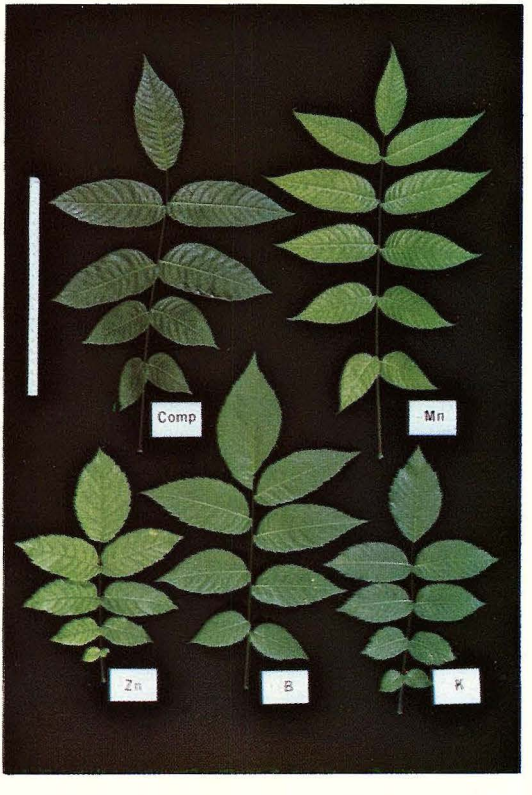


Fig. 27 (right).—Typical leaves of black walnut grown in various nutrient solutions. Top row: complete, —Mn; bottom row: —Zn, —B, —K.

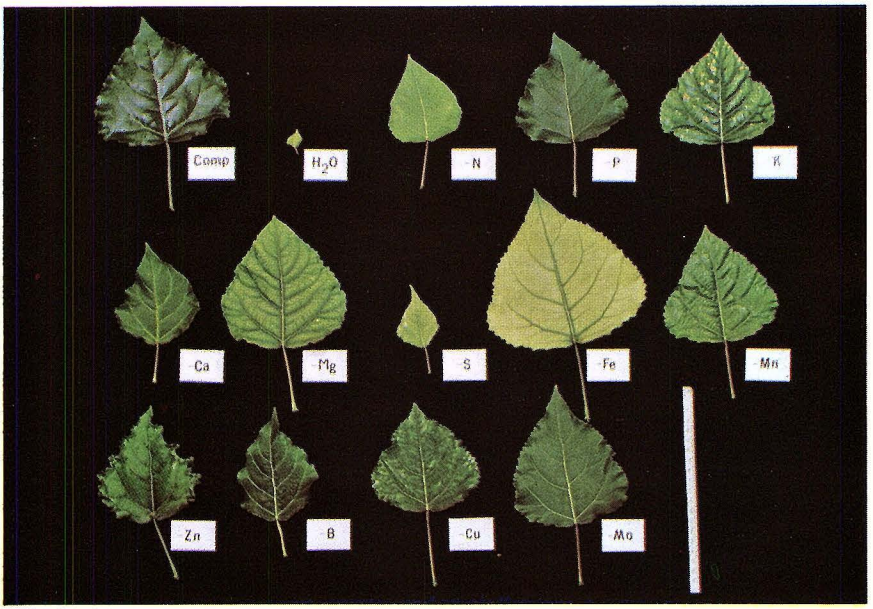


Fig. 28.—Typical leaves of cottonwood grown in various nutrient solutions. Top row: complete, deionized water, —N, —P, —K; middle row: —Ca, —Mg, —S, —Fe, —Mn; bottom row: —Zn, —B, —Cu, —Mo.

EFFECTS OF NUTRIENT DEFICIENCIES ON GROWTH AND DEVELOPMENT OF PLANT TOPS

The overall effects of the deficiencies on top growth of eastern cottonwood are shown in Figures 29-32, black locust in Figure 33, and sweetgum in Figure 34. Note the different patterns of development of the deficiency symptoms. In cottonwood, for example, potassium and magnesium symptoms appear first on the lower leaves. In contrast, calcium, iron, and boron affect the young developing tissues while nitrogen and sulfur deficiencies influence the whole plant uniformly. Copper deficiency seems to stimulate lateral branching.

Fig. 29.—Appearance of cottonwood cuttings grown for 77 days in complete, —N, —P, —K, and deionized water nutrient solutions.

Fig. 30.—Appearance of cottonwood cuttings grown for 77 days in complete, —Ca, —Mg, —S, and deionized water nutrient solutions.

Fig. 31.—Appearance of cottonwood cuttings grown for 77 days in complete, —Fe, —Mn, —Zn, and deionized water nutrient solutions.

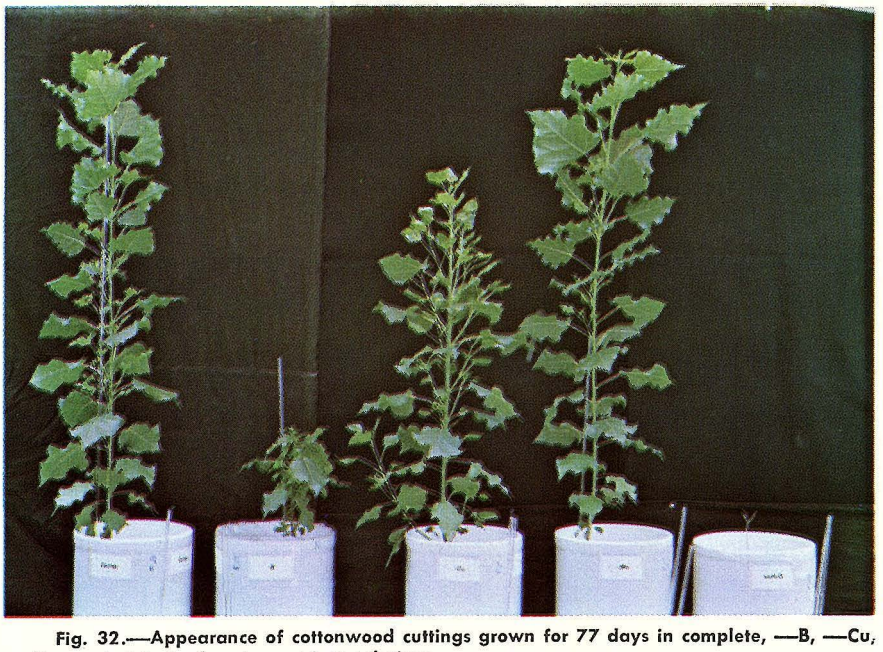
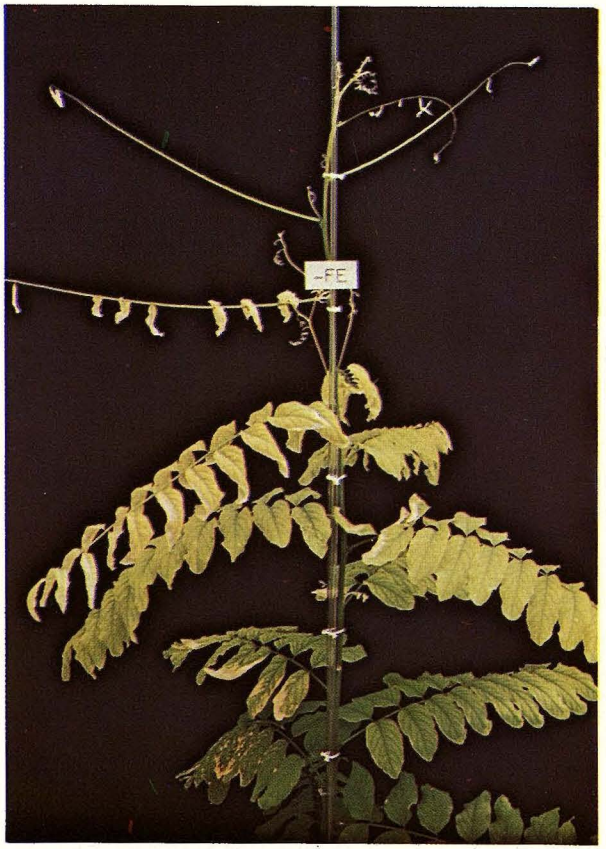


Fig. 32.—Appearance of cottonwood cuttings grown for 77 days in complete, —B, —Cu, —Mo, and deionized water nutrient solutions.

33A 33B 33C

Fig. 33.—Black locust grown in (A) complete, (B) potassium-deficient, and (C) magnesium-deficient nutrient solutions.

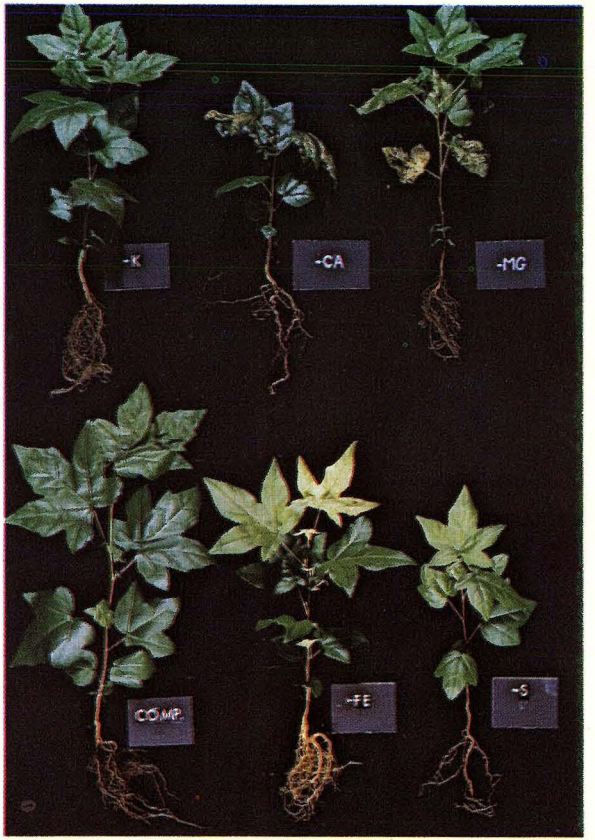


33D

33E

Fig. 33 (continued).—Black locust grown in (D) iron-deficient and (E) manganese-deficient nutrient solutions.

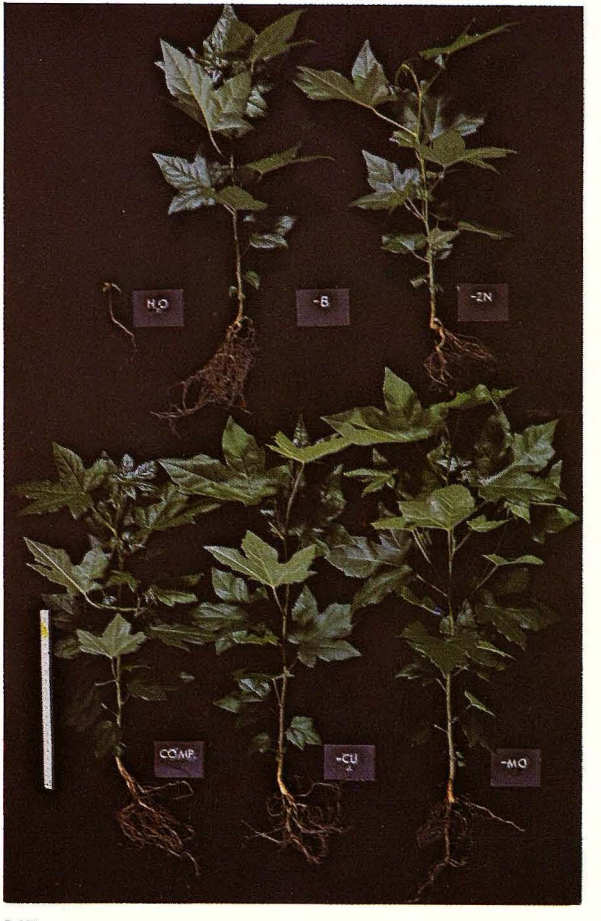
34A



34B

Fig. 34.—Sweetgum seedlings grown in various nutrient solutions. (A) Complete; top row: —Ca, —Mg, —Fe; bottom row: deionized water, —N, —P. (B) Top row: —K, —Ca, —Mg; bottom row: complete, —Fe, —S.

34C



34D

Fig. 34 (continued).—Sweetgum seedlings grown in various nutrient solutions. (C) Top row: deionized water, —Mg, —Fe; bottom row: complete, —Mn, —S. (D) Top row: deionized water, —B, —Zn; bottom row; complete, —Cu, —Mo.

GROWTH, DEVELOPMENT, AND COLOR OF ROOT SYSTEMS IN RELATION TO NUTRIENT DEFICIENCIES

Nutrient deficiencies often have as great or greater effects on roots as on the above-ground parts of the seedlings. Not only is size of the roots affected but also density, color, and, for black locust, nodulation. Composite photographs of roots of eastern cottonwood are shown in Figure 35, black walnut in Figure 36, and black locust in Figure 37. Root growth and other root characteristics of sweetgum are shown in the preceding photographs of the whole seedlings of this species (Figure 34).

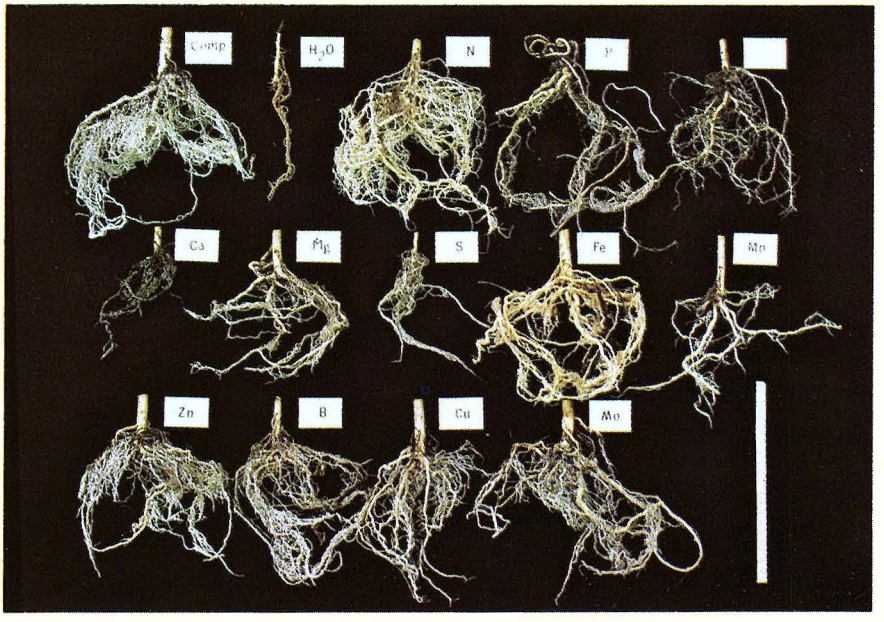
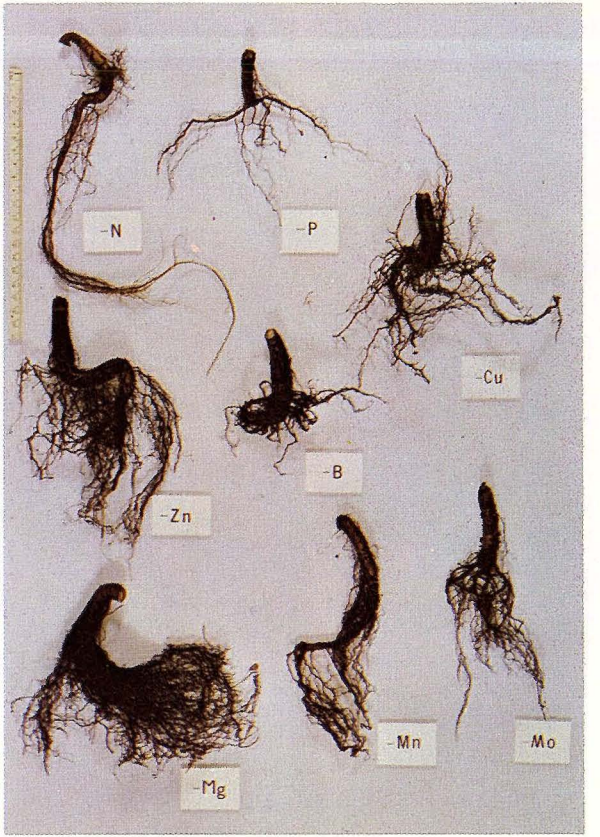
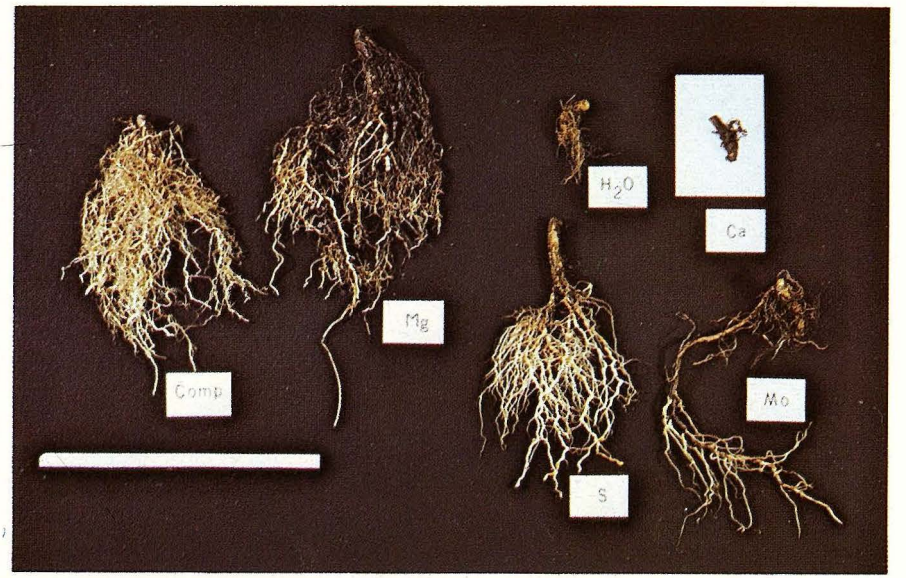


Fig. 35.—Root systems of eastern cottonwood grown in various nutrient solutions. Top row: complete, deionized water, —N, —P, —K; middle row: —Ca, —Mg, —S, —Fe, —Mn; bottom row: —Zn, —B, —Cu, —Mo.

36A



36B



36C

36D

Fig. 36.—Root systems of black walnut grown in various nutrient solutions. (A) Top row: complete, —Mn; bottom row: —Zn, —B, —K. (B) Top row: —N, —P; middle row: —Zn, —B, —Cu; bottom row: —Mg, —Mn, —Mo. (C) Complete, —Mg; top row: deionized water, —Ca; bottom row: —S, —Mo. (D) Complete; top row: —Ca; bottom row: —S, —Fe.

37A

37B

Fig. 37.—Root systems of black locust grown in various nutrient solutions. (A) Deionized water, —N, —B, —Mn; (B) complete, —Zn, —Cu, —Mo.

37C

37D

Fig. 37 (continued).—Root systems of black locust grown in various nutrient solutions. (C) —S, —K, —Ca, —P; (D) —Mg, —Fe.

RESULTS FOR SCOTS PINE

The effects of nutrient deficiencies in Scots pine are shown in Figure 38. Chemical analyses of the seedlings are given in Table 13.

No visible deficiency symptoms were found for seedlings in cultures from which Mn, Cu, Zn, or Mo were omitted and these are not included in the deficiency photographs. Color photographs were not available to illustrate boron deficiency symptoms.

Nutrient deficiency descriptions for Scots pine were abstracted from Goslin (5). Permission to use this material is gratefully acknowledged.

Nitrogen

Omission of nitrogen from the culture solution resulted in stunted seedlings with short primary leaves and no secondary leaves or laterals. The leaves were pale green with tips red or sometimes brown. Roots were brown to almost black and fibrous.

Phosphorus

Phosphorus-deficient seedlings were stunted and produced only primary leaves. Leaves were a blue-green color but died early, turning red-brown. Tips of leaves became purple starting on lower leaves; the purple changed to an olive green color and then to a brown necrosis extending toward the base of the leaves. Roots were sparse and purple-black with short laterals.

Potassium

Stems of potassium deficient seedlings were short and stout. Primary leaves remained a dark blue-green color. There was an abundance of lateral buds, prominent terminal buds, and long lateral stems. There were few or no secondary leaves. Roots were long and thread-like.

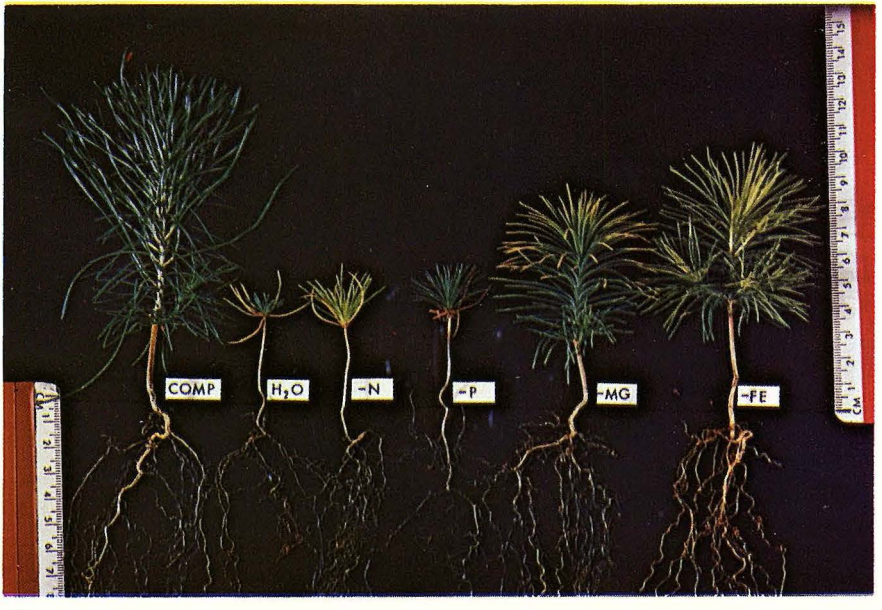
Calcium

Seedlings harvested at the end of the experiment had dead terminal buds. Adjacent buds were large and secondary leaves had a chlorotic band next to the stem. The secondary leaves developed necrosis, becoming red-brown. New secondary leaves at the terminal were short, pale at the base, and sometimes hooked at the tips. Ooze areas sometimes occurred in the midsection of secondary leaves. Roots were dark or blackish, showing some decomposition and surface tissue sloughing. They were fibrous above with rope-like thickening in lower parts and enlarged tips.

Sulfur

Sulfur-deficient seedlings were short with slender stems. Primary needles were blue-green, becoming pale yellowish green. Secondary leaves were abundant and short. Needle tips were often slightly red

38A



38B

Fig. 38.—Seedlings of Scots pine grown in various nutrient solutions. (A) Complete, —K, —S, —Ca; (B) complete, deionized water, —N, —P, —Mg, —Fe.

TABLE 13.—Concentrations of Elements in Leaves, Stems, and Roots of Scots Pine Determined for Seedlings Growing in Complete Solutions and in Deficient Nutrient Solutions.*

Element	Leaves		Stems		Roots	
	Complete	Deficient	Complete	Deficient	Complete	Deficient
			Percent			
P	0.15	0.02	0.22	0.02	0.48	0.03
K	1.36	0.47	1.51	0.43	2.14	0.43
Ca	0.48	0.09	0.36	0.07	0.47	0.08
Mg	0.19	0.02	0.21	0.01	0.17	0.01
			ppm			
Mn	605	88	116	24	75	4
Fe	49	15	23	25	3000	43
B	39	23	9	11	40	32
Cu	7	4	7	4	22	8
Zn	32	32	59	51	73	35
Mo	3	Trace	3	Trace	5	Trace

*Nitrogen and sulfur were not determined.

with faint yellowish spotting and banding. Lesions with resinous exudations occurred on the hypocotyl near the root. Roots were blackish, relatively abundant, but short. Longer roots were thread-like.

Magnesium

Tips of primary leaves of magnesium-deficient seedlings were pale yellow-orange and tips of secondary leaves were a bright yellow-orange starting at the tip and progressing along the entire length of the leaves. Cotyledons remained blue-green, as did the lower primary leaves. Roots were fibrous, short, and had a slimy gray appearance.

Iron

Leaves were pale yellow to cream color, sometimes with red tips. Newer leaves became chlorotic and the older ones retained their green color. Cotyledons remained green. The stems adjacent to the terminal buds soon died. The yellow leaves originating in this area died and became a light yellowish brown. Only a few long roots developed and these had thickened areas, strap-like in form with many root hairs.

APPLICATION OF RESULTS

Results obtained were for seedlings or rooted cuttings produced in one growing season in a nutrient solution from which one of the essential elements was omitted. However, a severe deficiency of one or more of the essential elements for older trees growing under natural conditions should result in comparable visual foliar deficiency symptoms. Under natural conditions, it is unlikely that any one of the essential plant nutrients would be completely lacking. Therefore, the symptoms illustrated here are examples of extreme deficiency which only occasionally are to be found in nature.

In forest tree nurseries, all of the nutrients contained in the plant are removed when the whole plant is harvested. Under these conditions, after repeated harvestings, macronutrient as well as micronutrient deficiencies may develop unless a proper regimen of fertilization is practiced.

Plantation trees growing on land formerly devoted to other crops may show one or more deficiency symptoms if the nutrients removed in the crops are not replaced by subsequent fertilization. Under these conditions, macronutrients would be removed in the largest quantities and deficiencies of these would probably be apparent first.

Trees growing on poor forest sites with low soil fertility levels may occasionally show pronounced visual foliar nutrient deficiencies.

PROCEDURE FOR IDENTIFYING A DEFICIENCY

Diagnostic criteria for nutrient deficiencies include leaf appearance, chemical composition of tissues, and the pattern of symptom development. The illustrations in this bulletin will be useful in making a tentative diagnosis.

A tentative diagnosis may be confirmed by spraying or painting a dilute solution of a soluble salt of the element on the deficient leaves (12). Disappearance of the symptoms after 1 or 2 weeks indicates a correct identification of the deficient element. If the symptoms persist, solutions of other elements can be tried. Analyses of the deficient leaves and comparison with tables in this bulletin will indicate which elements are at the deficiency level.

CORRECTION OF DEFICIENCIES

The quantity of soil nutrients may be ample for a plant's needs but the elements may occur in a chemically unavailable form. Even though the elements are present in suitable form, conditions such as poor soil aeration may hinder absorption. Hydrogen ion concentration (pH), soil moisture, light intensity, and presence or absence of mycorrhizae may significantly affect mineral uptake. Therefore, it should be determined that soil conditions and other environmental factors are at levels

satisfactory for normal tree growth before poor growth is attributed to nutrient deficiencies.

If a nutrient deficiency results directly from the low quantity present in the soil and is not due to conditions previously mentioned, the deficiency can usually be corrected by application of suitable fertilizers. However, a knowledge of soils and plant nutrient requirements is necessary to effectively prescribe the time, form, and quantity of fertilizers which should be applied and the method of placement. The U. S. Forest Service, State Agricultural Experiment Stations, Cooperative Extension Service, State Foresters, and consulting foresters can supply advice and guidance for a fertilization program.

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APPENDIX

TABLE I.—Composition of Nutrient Solutions.

Compounds	Comp.	—N	—P	—K	—Ca	—Mg	—S	—Fe	—B	—Zn	—Cu	—Mn	—Mo
	Number of Millimoles of Compound Added per Liter of Nutrient Solution												
KNO_3	2		2		2	2	2	2	2	2	2	2	2
KH_2PO_4	2	2			2	2	2	2	2	2	2	2	2
$Ca(NO_3)_2 \cdot 4H_2O$	3		3	3		3	3	3	3	3	3	3	3
$MgSO_4 \cdot 7H_2O$	2	2	2	2				2	2	2	2	2	2
KCl		2	2										
$CaCl_2$		3											
Na_2SO_4					2	2							
NaH_2PO_4				2									
$NaNO_3$				2									
$Mg(NO_3)_2$					3								
$MgCl_2$							2						
	Number of Micromoles per Liter of Nutrient Solution												
Fe-EDTA	89	89	89	89	89	89	89	0	89	89	89	89	89
H_3BO_3	37	37	37	37	37	37	37	37	0	37	37	37	37
$MnCl_2 \cdot 4H_2O$	7	7	7	7	7	7	7	7	7	7	7	0	7
$ZnCl_2$	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0	0.76	0.76	0.76
$CuCl_2 \cdot 2H_2O$	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0	0.31	0.31
MoO_3	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0

TABLE IIA.—Concentration of Nutrient Elements in Leaves of Black Walnut Grown in Various Nutrient Solutions.

Nutrient Solution	N	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
	Percent of Oven-Dry Weight						Parts per Million					
Complete	3.35	0.34	1.72	1.19	0.40	0.20	202	95	25	41	11	2.1
—N	**2.96**	0.28	1.16	1.18	0.42	0.18	775	184	62	41	14	1.8
—P	3.52	**0.17**	1.38	0.98	0.36	0.20	814	178	51	53	11	0.8
—Ca	2.98	0.20	0.75	**0.30**	0.37	0.22	122	40	62	41	14	0.8
—Mg	2.91	0.27	1.68	1.24	**0.06**	0.15	537	82	39	46	6	0.5
—S	4.22	0.43	1.90	1.41	0.47	**0.14**	311	167	41	79	16	9.5
—Fe	3.14	0.37	1.87	2.23	0.63	0.22	**262**	315	52	65	19	3.9
—Mn	3.05	0.32	1.90	1.16	0.40	0.17	254	**15**	34	45	12	1.7
—Zn	2.87	0.29	1.12	0.92	0.34	0.19	263	115	**48**	46	12	1.2
—B	3.21	0.33	1.75	0.99	0.37	0.24	364	113	27	**40**	12	2.0
—Cu	3.11	0.29	1.53	1.06	0.36	0.15	252	118	31	48	**8**	1.7
—Mo	2.70	0.34	1.36	1.46	0.47	0.19	287	114	50	52	13	**2.3**

TABLE IIB.—Concentration of Nutrient Elements in Stems of Black Walnut Grown in Various Nutrient Solutions.

Nutrient Solution	N	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
	Percent of Oven-Dry Weight						Parts per Million					
Complete	1.86	0.25	0.76	0.42	0.15	0.12	44	26	11	12	8	0.2
—N	**1.62**	0.16	0.54	0.53	0.14	0.06	97	127	15	29	9	0.1
—P	2.02	**0.13**	0.76	0.48	0.14	0.07	110	88	30	21	10	<0.1
—Ca	1.76	0.37	1.09	**0.07**	0.33	0.06	49	44	28	24	15	0.6
—Mg	1.22	0.21	0.70	0.92	**0.04**	0.07	20	31	12	9	6	<0.1
—S	2.77	0.38	1.06	0.52	0.17	**0.02**	75	47	26	35	14	0.2
—Fe	2.35	0.31	1.33	0.55	0.18	0.11	**32**	55	28	20	16	0.2
—Mn	2.47	0.27	0.84	0.46	0.15	0.14	55	**9**	14	18	11	0.2
—Zn	1.92	0.26	0.68	0.40	0.15	0.10	84	39	**19**	22	12	0.1
—B	2.03	0.28	0.97	0.49	0.16	0.17	125	48	14	**21**	9	0.2
—Cu	1.66	0.25	0.88	0.46	0.14	0.10	58	33	13	22	**9**	0.1
—Mo	2.37	0.26	0.79	0.48	0.18	0.13	102	38	19	30	9	**0.1**

TABLE IIC.—Concentration of Nutrient Elements in Roots of Black Walnut Grown in Various Nutrient Solutions.

Nutrient Solution	N	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
	Percent of Oven-Dry Weight						Parts per Million					
Complete	2.78	0.38	1.26	0.31	0.17	0.15	906	132	16	22	11	1.2
—N	**1.85**	0.28	0.74	0.26	0.15	0.07	615	138	33	28	10	0.2
—P	2.28	**0.24**	0.69	0.19	0.11	0.15	846	51	28	20	22	0.8
—Ca	2.38	0.49	0.88	**0.05**	0.55	0.24	1049	57	28	37	33	4.8
—Mg	2.43	0.36	0.86	0.83	**0.05**	0.12	703	83	15	17	8	0.5
—S	3.92	0.62	2.02	0.42	0.18	**0.08**	866	329	32	60	19	9.3
—Fe	2.79	0.50	2.47	0.36	0.21	0.17	**581**	314	31	35	63	1.2
—Mn	2.96	0.39	0.98	0.23	0.17	0.17	1154	**11**	19	23	22	3.6
—Zn	3.04	0.38	0.50	0.23	0.14	0.13	1302	60	**33**	33	40	7.9
—B	2.85	0.40	1.13	0.20	0.16	0.18	1246	48	19	**21**	22	6.6
—Cu	2.56	0.31	0.62	0.16	0.11	0.16	1187	28	16	20	**12**	4.9
—Mo	3.11	0.47	0.92	0.39	0.20	0.18	1398	83	49	49	24	**1.0**

TABLE IIIA.—Concentration of Nutrient Elements in Leaves of Cottonwood After 77 Days' Growth in Various Nutrient Solutions.

Nutrient Solution	N	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
	Percent of Oven-Dry Weight						Parts per Million					
Complete	2.86	0.83	4.59	0.95	0.49	0.378	90	49	14	68	2.2	1.3
—N	**1.38**	1.47	4.16	1.61	0.37	0.306	79	69	64	66	10.4	1.1
—P	2.74	**0.14**	3.86	0.96	0.30	0.331	108	63	61	64	6.0	0.9
—K	2.56	1.48	**0.44**	1.61	0.99	0.490	45	82	35	82	16.1	8.2
—Ca	2.01	0.71	2.85	**0.20**	0.53	0.294	53	36	27	31	<2.7	1.2
—Mg	2.74	1.02	6.54	1.08	**<0.04**	0.497	79	57	30	62	<2.6	0.4
—S	2.80	1.97	5.87	1.46	0.46	**0.128**	100	167	74	85	Tr.*	>9.0
—Fe	3.34	1.06	4.60	1.17	0.60	0.450	**33**	127	36	79	<4.9	2.2
—Mn	4.17	0.93	4.80	0.98	0.58	0.469	95	**<9**	36	78	2.0	1.8
—Zn	3.04	0.86	4.96	1.22	0.64	0.547	87	85	**36**	98	4.4	3.7
—B	2.61	0.77	4.33	1.12	0.27	0.438	65	96	48	**9**	4.0	1.2
—Cu	3.55	0.84	4.41	1.12	0.47	0.481	97	47	23	62	**Tr.***	1.4
—Mo	3.14	0.93	5.10	1.15	0.67	0.503	95	46	29	>85	<2.5	**1.8**

*Tr. = Trace

TABLE IIIB.—Concentration of Nutrient Elements in Stems of Cottonwood After 77 Days' Growth in Various Nutrient Solutions.

Nutrient Solution	N	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
	Percent of Oven-Dry Weight						Parts per Million					
Complete	1.01	0.43	1.46	0.46	0.17	0.051	24	9	8	13	0.6	0.3
—N	**0.41**	0.56	1.68	0.81	0.14	0.012	27	18	44	18	1.7	0.3
—P	0.97	**0.05**	1.72	0.72	0.16	0.106	23	19	57	17	<3.1	0.3
—K	0.85	0.47	**0.20**	0.67	0.16	0.050	17	16	37	16	4.0	0.4
—Ca	1.10	0.72	1.62	**0.15**	0.47	0.137	19	18	27	18	3.7	0.7
—Mg	0.80	0.60	1.49	1.18	<**0.04**	0.090	16	17	20	16	2.5	0.2
—S	1.60	1.04	1.35	0.81	0.20	**0.038**	18	48	36	16	Tr.	>9.0
—Fe	1.03	0.53	1.71	0.59	0.22	0.096	**11**	30	22	18	3.4	0.5
—Mn	1.12	0.49	1.25	0.61	0.25	0.053	18	<**9**	18	17	2.8	0.2
—Zn	1.37	0.47	1.54	0.53	0.24	0.168	28	22	**26**	16	4.0	0.7
—B	2.34	0.75	2.50	0.96	0.21	0.172	32	33	34	**7**	3.5	0.5
—Cu	1.37	0.54	2.04	0.56	0.24	0.078	25	13	16	15	**2.8**	0.4
—Mo	1.28	0.57	1.86	0.54	0.26	0.084	37	14	21	19	3.4	**0.7**

TABLE IIIC.—Concentration of Nutrient Elements in Roots of Cottonwood After 77 Days' Growth in Various Nutrient Solutions.

Nutrient Solution	N	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
	Percent of Oven-Dry Weight						Parts per Million					
Complete	1.27	0.91	2.06	0.83	0.24	0.178	925	37	13	15	8.0	0.7
—N	**0.50**	0.93	2.12	0.70	0.13	0.100	1032	42	66	37	12.9	1.4
—P	0.81	**0.10**	1.69	0.75	0.14	0.188	1374	74	33	37	11.7	0.4
—K	1.25	1.30	**0.22**	1.27	0.33	0.163	1050	200	32	22	5.3	2.8
—Ca	1.00	0.63	0.74	**0.15**	0.53	0.203	1300	37	29	21	12.5	1.8
—Mg	0.98	1.39	0.86	1.92	<**0.04**	0.172	884	188	29	17	13.0	0.5
—S	1.27	1.29	1.42	0.86	0.18	**0.041**	1440	182	47	18	8.1	>9.0
—Fe	1.31	1.03	2.12	0.85	0.24	0.188	**74**	108	36	18	30.0	1.6
—Mn	1.35	1.21	1.66	0.95	0.22	0.131	534	<**9**	18	16	3.0	0.5
—Zn	1.31	0.90	2.21	0.78	0.27	0.090	588	44	**42**	16	6.6	1.2
—B	1.94	1.23	2.66	1.25	0.18	0.197	728	204	36	**10**	12.0	1.2
—Cu	1.53	1.05	2.18	0.69	0.23	0.131	656	44	18	15	<**2.5**	0.5
—Mo	1.65	1.24	2.91	1.08	0.38	0.244	1250	50	32	23	5.0	**1.2**

TABLE IVA.—Concentration of Nutrient Elements in Leaves of Black Locust Grown in Various Nutrient Solutions.*

Nutrient Solution	N	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
	Percent of Oven-Dry Weight						Parts per Million					
Complete	2.89	0.44	2.38	1.11	0.41	0.16	135	47	34	73	17	1.7
—N	**2.07**	0.90	2.86	1.67	0.42	0.21	298	71	47	70	16	2.3
—P	2.61	**0.08**	1.63	1.10	0.41	0.12	219	82	38	43	29	2.3
—K	3.47	0.55	**0.54**	1.74	0.85	0.25	140	61	39	89	28	4.8
—Ca	3.20	0.45	2.26	**0.28**	0.56	0.15	268	55	30	46	24	4.2
—Mg	3.11	0.45	2.89	1.17	**0.20**	0.17	112	38	36	62	9	0.8
—S	3.50	0.50	2.57	1.67	0.53	**0.12**	159	52	40	69	31	2.7
—Fe	3.00	0.42	2.51	1.12	0.43	0.15	**93**	43	33	61	9	1.9
—Mn	4.46	0.46	2.99	1.26	0.44	0.19	97	**18**	36	28	14	1.2
—Zn	3.19	0.39	2.36	1.06	0.40	0.17	135	29	**36**	35	19	2.0
—B	3.51	0.41	2.57	1.13	0.40	0.14	86	28	32	**8**	12	1.2
—Cu	2.80	0.43	2.05	1.05	0.34	0.13	113	25	26	27	**19**	1.3
—Mo	3.41	0.47	2.37	1.15	0.36	0.19	121	32	29	52	18	**1.2**

*Marsh, Barbara. 1965. The effects of mineral deficiencies on the accumulation of other minerals and visual symptoms displayed by black locust. Senior Independent Study, College of Wooster, Wooster, Ohio.

TABLE IVB.—Concentration of Nutrient Elements in Stems of Black Locust Grown in Various Nutrient Solutions.

Nutrient Solution	N	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
	Percent of Oven-Dry Weight						Parts per Million					
Complete	0.94	0.33	1.11	0.44	0.17	0.09	16	17	19	12	4	1.7
—N	**0.93**	0.46	1.34	0.81	0.20	0.20	36	20	36	13	15	4.4
—P	1.27	**0.06**	0.63	0.68	0.17	0.04	17	17	30	16	8	2.8
—K	1.55	0.32	**0.31**	0.49	0.22	0.14	19	17	36	10	7	4.3
—Ca	1.98	0.43	1.00	**0.13**	0.34	0.11	16	23	22	14	4	4.0
—Mg	1.18	0.36	1.61	0.71	**0.12**	0.11	18	17	27	9	4	1.7
—S	1.90	0.36	1.09	0.55	0.18	**0.04**	16	16	28	10	5	2.9
—Fe	1.13	0.34	1.69	0.47	0.20	0.11	**19**	18	27	12	10	2.3
—Mn	1.88	0.42	1.76	0.58	0.20	0.13	22	**13**	24	6	7	0.9
—Zn	1.18	0.31	0.94	0.38	0.17	0.09	22	15	**23**	11	8	0.7
—B	2.83	0.47	1.15	0.64	0.27	0.14	25	17	25	**7**	5	1.4
—Cu	1.63	0.37	0.84	0.49	0.17	0.07	15	13	17	10	**4**	0.8
—Mo	1.56	0.37	1.01	0.47	0.17	0.10	16	14	20	17	4	**0.6**

TABLE IVC.—Concentration of Nutrient Elements in Roots of Black Locust Grown in Various Nutrient Solutions.

Nutrient Solution	N	P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
	Percent of Oven-Dry Weight						Parts per Million					
Complete	1.85	0.80	3.03	1.40	0.65	0.64	916	91	24	31	16	5.0
—N	**2.06**	0.88	3.67	0.52	0.41	0.51	636	181	58	13	16	5.0
—P	2.71	**0.09**	1.88	1.16	0.48	0.17	443	104	33	21	28	3.5
—K	2.59	0.86	**0.27**	1.73	0.51	0.45	966	178	31	16	19	5.0
—Ca	2.68	0.54	1.86	**0.21**	0.66	0.19	395	109	27	37	15	4.1
—Mg	2.02	0.65	2.23	1.30	**0.16**	0.34	561	73	42	14	16	3.4
—S	2.80	0.71	1.91	1.16	0.47	**0.06**	744	113	27	12	15	4.9
—Fe	2.03	0.68	3.16	0.85	0.55	0.43	**269**	73	38	17	7	5.0
—Mn	2.56	0.77	2.76	1.35	0.62	0.28	823	**18**	34	21	12	4.0
—Zn	2.20	0.82	2.26	1.57	0.53	0.32	910	26	**28**	5	17	3.4
—B	3.85	0.72	2.33	1.05	0.40	0.25	605	28	32	**19**	9	2.4
—Cu	2.66	0.72	2.63	1.20	0.48	0.26	716	28	21	4	**6**	2.9
—Mo	2.62	0.72	2.23	1.17	0.48	0.32	726	27	22	10	10	**2.0**

TABLE VA.—Concentration of Nutrient Elements in Leaves of Scots Pine Grown in Various Nutrient Solutions.

Nutrient Solution	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo
	Percent of Oven-Dry Weight				Parts per Million					
Complete	0.15	1.36	0.48	0.19	49	605	32	39	7	3
—N	0.08	2.18	0.86	0.39	27	790	63	27	4	5
—P	**0.02**	1.88	0.48	0.18	127	314	111	36	9	2
—K	0.12	**0.47**	0.47	0.29	30	314	41	37	5	3
—Ca	0.15	1.21	**0.09**	0.35	49	706	56	50	10	4
—Mg	0.09	2.06	0.79	**0.02**	62	1604	112	35	7	5
—S	0.15	1.99	0.63	0.26	35	1011	60	37	8	26
—Fe	0.14	3.11	0.83	0.31	**15**	529	106	32	3	9
—Mn	0.17	1.23	0.40	0.18	53	**88**	44	26	6	3
—Zn	0.18	1.45	0.46	0.17	39	457	**32**	35	5	5
—B	0.22	1.73	0.41	0.20	57	437	18	**23**	4	2
—Cu	0.13	1.36	0.40	0.17	35	605	21	31	**4**	3
—Mo	0.16	1.62	0.43	0.20	46	649	20	38	5	**Tr.**

TABLE VB.—Concentration of Nutrient Elements in Stems of Scots Pine Grown in Various Nutrient Solutions.

Nutrient Solution	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo
	Percent of Oven-Dry Weight				Parts per Million					
Complete	0.22	1.51	0.36	0.21	23	116	59	9	7	3
—N	0.31	1.84	0.58	0.36	129	51	69	14	16	5
—P	**0.02**	1.49	0.53	0.34	268	32	71	8	22	3
—K	0.14	**0.43**	0.36	0.31	78	32	76	6	10	3
—Ca	0.22	1.13	**0.07**	0.47	110	289	76	11	10	3
—Mg	0.10	1.61	0.68	**0.01**	62	366	112	6	9	4
—S	0.21	1.49	0.53	0.42	96	383	67	7	9	18
—Fe	0.26	1.88	0.52	0.42	**25**	52	91	11	4	4
—Mn	0.20	1.26	0.37	0.30	105	**24**	58	6	6	3
—Zn	0.26	1.59	0.28	0.24	28	40	**51**	9	5	3
—B	0.25	1.77	0.38	0.31	19	50	45	**11**	4	3
—Cu	0.19	1.91	0.36	0.20	592	159	49	7	**4**	2
—Mo	0.19	1.69	0.44	0.28	54	78	47	9	5	**Tr.**

TABLE VC.—Concentration of Nutrient Elements in Roots of Scots Pine Grown in Various Nutrient Solutions.

Nutrient Solution	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo
	Percent of Oven-Dry Weight				Parts per Million					
Complete	0.48	2.14	0.47	0.17	3000	75	73	40	22	5
—N	0.53	1.81	0.34	0.38	5251	38	115	79	13	33
—P	**0.03**	1.27	0.34	0.16	621	25	104	29	17	3
—K	0.31	**0.43**	0.40	0.74	2357	25	51	54	9	5
—Ca	0.33	1.35	**0.08**	0.60	2787	129	88	39	15	6
—Mg	0.28	1.52	0.47	**0.01**	3029	38	143	38	17	7
—S	0.67	2.41	0.29	0.28	3587	565	48	72	7	17
—Fe	0.60	2.58	0.45	0.37	**43**	164	313	50	13	20
—Mn	0.29	1.62	0.36	0.20	2586	**4**	79	57	9	5
—Zn	0.48	1.90	0.53	0.26	2062	14	**35**	51	8	2
—B	0.45	1.78	0.67	0.28	2504	20	40	**32**	7	Tr.
—Cu	0.41	1.66	0.51	0.19	2765	68	58	51	**8**	4
—Mo	0.41	2.11	0.52	0.30	3687	26	22	64	10	**Tr.**

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